QA/QC Research Report

Submitted to the Department of Resources Recycling and Recovery (CalRecycle)

Prepared by: Manex Consulting

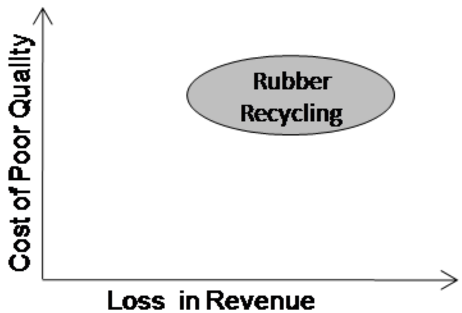
Table of contents

I. Objective of Study (1 of 5)

- **Overarching Objective**
  - To contribute to the reduction of tires sent to nation's landfill each year – 303 million currently
  - To reduce oil consumption – more than 1.5 gallons is consumed to make one pound of synthetic rubber
    - Producing one pound of recycled rubber requires only 29% of the energy used for virgin rubber
  - To reduce or eliminate operational deficiencies within the rubber recycling value chain
    - Operational deficiencies cause 40 million tires to go to the landfills every year
    - Inefficient and poor scheduling practices by haulers who work for manufacturers encourages the non-manufacturing haulers to pick more tires and put them into landfills
    - Gamut of operational issues (e.g. not able to grind due to frequent machine breakdowns) causes more tires to be diverted to landfill from the processing site
    - Lack of quality and consistency in recycled rubber products forces some of the consumers to switch to virgin rubber products
    - Today, a business in rubber recycling makes more margin by hauling tires than by processing those tires into other usable forms. This encourages these businesses to landfill tires.
    - Environmental Impact: Tires do not significantly decompose when buried. They have a tendency to rise to the surface and compromise the suitability of the landfill sites for future development. Tires improperly disposed of, either in landfills or left on the surface of the ground, provide excellent breeding grounds for diseases, carrying microbes and pests. Huge tire stockpiles have proven to be a threat to public safety and environmental quality. Moreover, fires that arise in such stockpiles are costly and difficult to control.
    - For 3 straight years the number of tires diverted *from* landfills has *dropped* – a fact that is of concern
  - To enable recycled rubber as a primary alternative to replace several Synthetic-rubber/virgin-rubber based products
    - Recycled rubber can replace a multitude of products made from virgin rubber, only if the quality and consistency between the two is equal
  - Enabling establishment of acceptable level of quality requirements and regulatory compliances
  - Enable perception change among consumer groups
    - The production and sale of poor quality recycled rubber products has led to the perception that recycled rubber products are unsafe

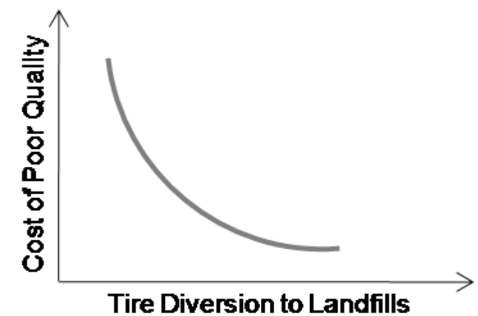
I. Objective of Study (2 of 5)

- **The case for quality:** Consider a manufacturer with annual revenue of $10 mm. Due to poor quality processes, the costs incurred towards poor quality (or COPQ – Cost of Poor Quality) at various quality levels are:
  - If COPQ is 5% of total revenue : Loss due to poor quality = $500K
  - If COPQ is 15% of total revenue : Loss due to poor quality = $ 1.5 mm
  - If COPQ is 25% of total revenue : Loss due to poor quality = $2.5 mm
  - If COPQ is 30% of total revenue : Loss due to poor quality = $3 mm



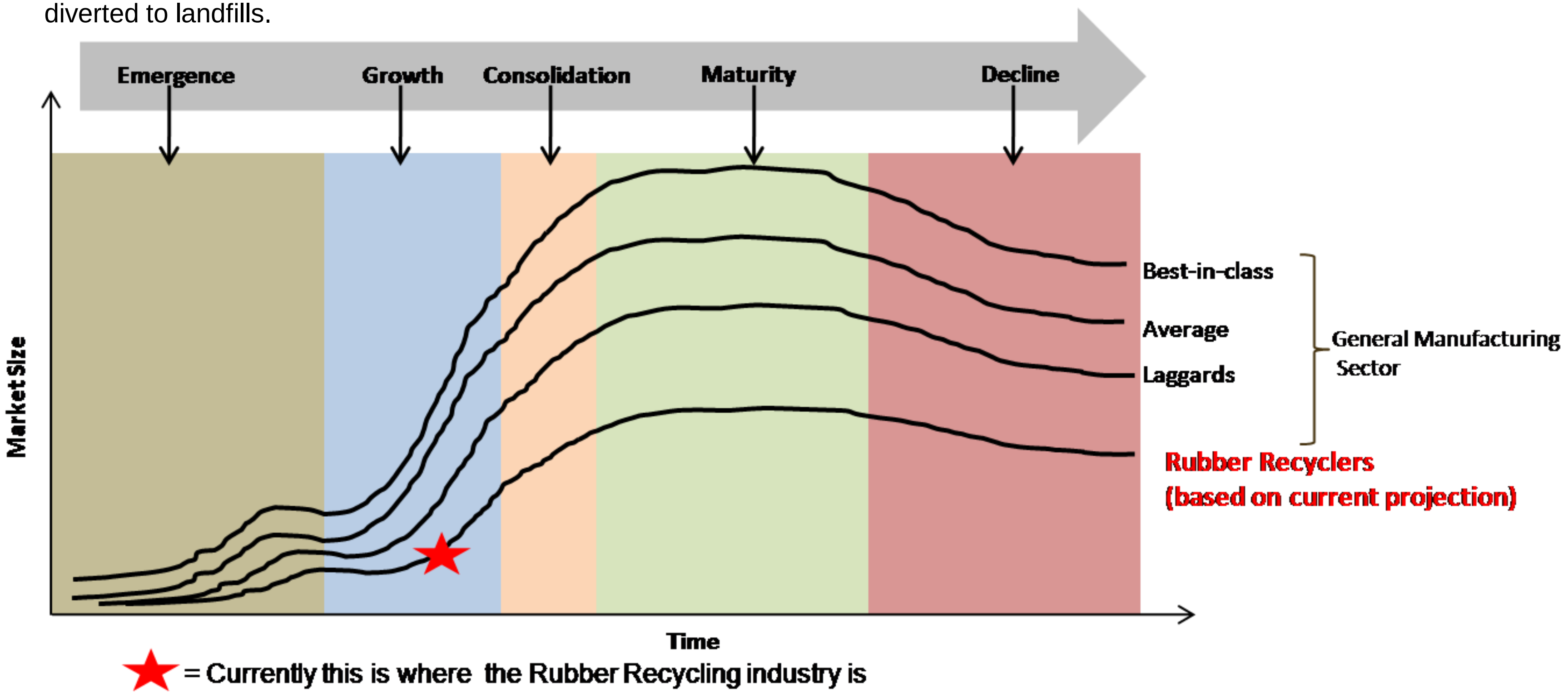
On average, a manufacturer loses between 15% - 30% of its revenue due to poor quality processes and practices

The First-Pass-Yield for a typical Rubber Recycler is below 50% - meaning extensive rework and rejects



- Significant costs incurred to address poor quality have eroded margins for businesses, especially processors and manufacturers, prompting them to reconsider the viability of the rubber recycling business. Some of the businesses have already left the industry, while some are desperately struggling to meet ends. A drop in the number of businesses that recycle used tires will lead to an increase in scrap tire diversion to the landfills.
- Production and sale of poor quality recycled rubber products has led to an "unsafe" perception of some of the recycled rubber products. In some cases, the product and final installation fail to comply with the ADA (American Disability Act) requirements.
- Due to inefficient manufacturing practices and several quality issues, market adoption of recycled rubber products is significantly lower than it should be. We estimate that the current market adoption is between 65% – 75% of what it should be.
- A poorly connected rubber recycling supply chain and inefficient communication and operations within this supply chain are other important reasons for poor market adoption of recycled rubber products. This in turn causes an increase in scrap tire diversion to the landfills.

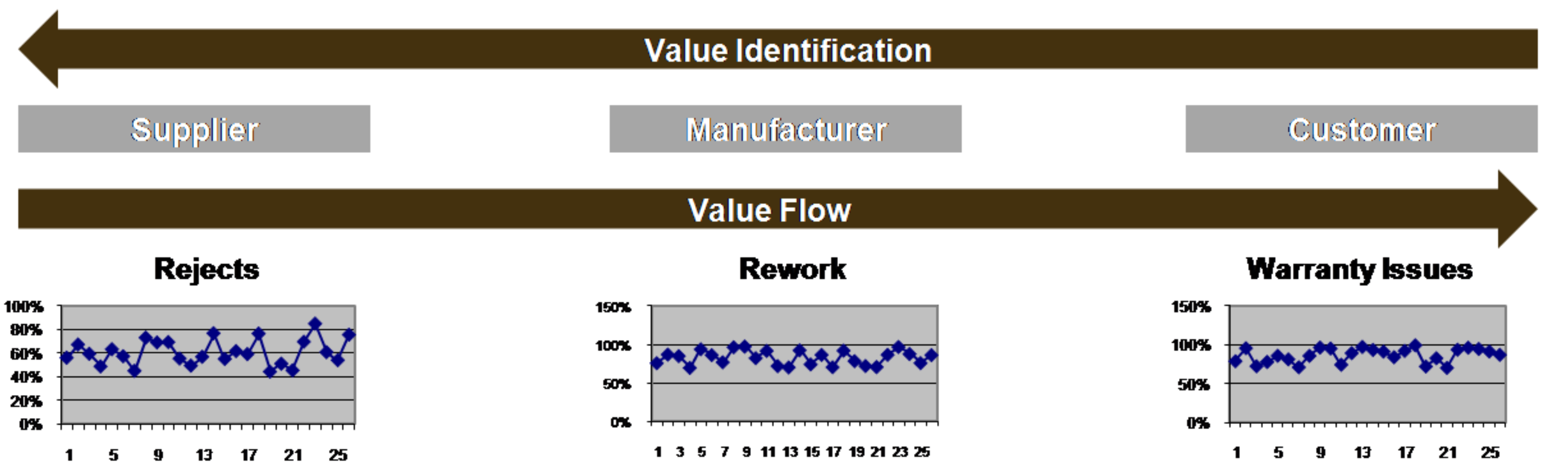
- During our research, we found that when a typical recycled rubber manufacturer/processor is compared with the general manufacturing industry, the recycler fares poorly in terms of growth of market size during the life cycle of a product. We also determined that existence of an established quality management system with functioning Quality Assurance/Quality Control (QA/QC) is positively correlated with growth in market size during the life cycle of a product. The chart below depicts our findings. It should be noted that the quality level increases as the companies move from being in the 'Laggard' category to 'Best-in-Class' category.
- Our findings subsequently lead us to conclude that, on an average, the manufacturers/processors within the rubber recycling realm have below standard quality practices and lack an efficient QA/QC program. This is one of the significant factors that is impeding their growth and consequently affecting the market adoption of recycled rubber products, leading to more tires being diverted to landfills.



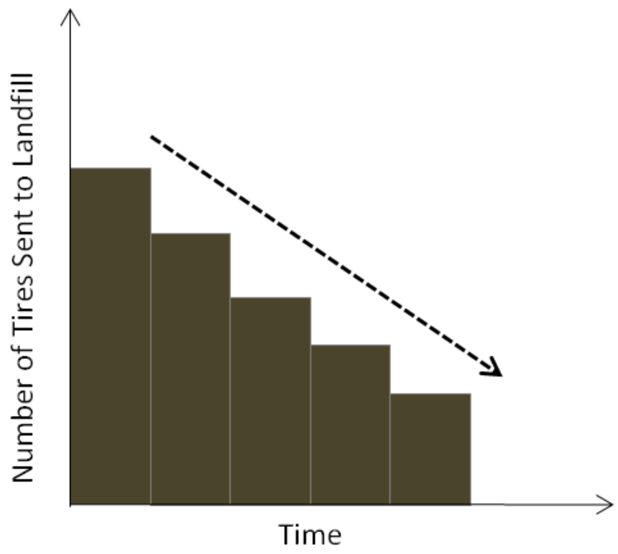
I. Objective of Study (4 of 5)

- **Increasing Tire Diversion Using QAQC**
  - Focus on the overall operation within the <u>*entire*</u> value stream
  - Identify the factors that affect the quality of a product during various stages of the operation
  - From the quality perspective, identify the critical control points within the value stream
  - Understand and define customer expectations from the QA/QC perspective
  - Establish standards and develop quality systems to ensure high quality product consistency
  - Develop the KPI's to measure and monitor quality
  - Develop supplier quality metrics to monitor supplier performance
  - Using the metrics and KPI's established, identify the root cause of existing problems
  - Understand the substitutes for virgin rubber materials from the Quality perspective
  - Establish QA/QC parameters for nonrecycled rubber products to establish standards for recycled rubber
  - Identify established industry standards and specifications for QA/QC
  - Identify best practices within the rubber recycling industry, using standards from other markets

The lack of industry standards (e.g. 99% on-time delivery or 95% product quality) and key performance metrics (e.g. 14 day lead times) has severely constrained the growth of scrap tire derived products



- **Our efforts will have a two-fold impact**
  - Environmental: Decrease in the number of tires sent to the landfill
  - Business: Increase in the business viability and revenue stream of the rubber recyclers



Environmental Impact: Decease in number of tires sent to the landfill over a period of time

Business Impact: Increase in business viability and revenue stream of the rubber recyclers through adoption of best practices

II. Executive Summary (1 of 2)

The Quality Assurance/Quality control (QA/QC) research report is a compendium of information primarily targeted at the rubber recycling industry and the rubber recycling supply chain, which includes Haulers, Processors, Manufacturers and Distributors. The report spans the gamut of information gathered from controlled surveys, interviews and site visits. The report also has information gathered from rubber recycling industry specific research papers, trade journals, industry groups, and other subject matter experts. Proven methodologies have been discussed in this report with a two-fold objective: reducing the number of tires diverted to landfills and improving the business operations of the entities in the rubber recycling supply chain. Industry best practices and standards and specifications have been comprehensively discussed in this report to aid the primary audiences.

The report begins with the reason this document was generated and the importance of this report given the situation – current QA/QC system – the rubber recycling supply chain is in. This section makes the case for quality and what the impacts of poor quality could be. In the next section quality has been defined, and ways of managing quality have been discussed. Quality Assurance/Quality Control and how this impacts the supply chain have been discussed in-depth in the next section. The report also comprehensively discusses an important question: "How can I improve my quality". It is key to understand how and where to apply Quality Assurance (QA) and Quality Control (QC). Although there are many QA/QC tools, Pareto Analysis, Fishbone diagram, 5Why analysis, Impact-Effort chart and the roadmap for improvement have been discussed in this report. The report then moves on to a discussion on benefits of effective QA/QC practices, QA/QC issues specific to the rubber recycling supply chain and the top issues facing the supply chain. This section is wrapped-up with a discussion on Best-in-Class performance, an in-depth discussion on Cost of Quality and on the Quality Management Systems (QMS).

II. Executive Summary (2 of 2)

The next section goes into details of some of the common issues faced by the rubber recycling industry. These issues were determined from the feedback we received from the companies in the rubber recycling industry and from the interviews with subject matter experts. Common practices/issues such as storage quality, cryogenic processing, hot molding, moisture retention, contaminates, binders, bonding agents etc. have been discussed. The next section discusses some of the industry specific Standards and Specifications that can be used throughout the rubber recycling supply chain. Primarily, an overview of ASTM standards has been discussed in this section. A high level overview of standards such as the ones used for testing playgrounds, measuring pour density, deterioration, relative aberration resistance, effects of liquids and water hardness, product contamination and others have been mentioned in this section.

The next section reflects on why the rubber recycling industry has not yet gained traction followed by a section on Best Practices on how to create an organization producing quality products. The Best Practices section discusses in brief some of the methodologies commonly used such as Supply Chain management, Lean Manufacturing, Six Sigma and Total Quality Management. Finally, the report discusses six QA/QC specific case studies to provide insights and examples about the execution and benefits of implementing a QA/QC program.

III. Defining Quality

- Definitions
  - Conformance to specifications : Philip B. Crosby
  - Fitness for intended use : Dr. Joseph M. Juran
  - Totality of features and characteristics of a product or service that bear on its ability to satisfy given needs: American Society for Quality
  - That which makes something what it is: Webster's Dictionary
- Practical Definition
  - Quality is a reflection of the processes and the work that yields products and services
    - Quality is tied to product characteristics, which is controlled by process parameters
    - Quality depends on the amount customers are willing to pay

Managing Quality (1 of 2)

- Effective quality management ensures that quality requirements are practical, enforceable, necessary and verifiable
- Effective quality management program will assign responsibilities and authorities, define policies and requirements, and provide for the performance and assessment of quality activities
- Effective quality management program will address the following key attributes:
  - Measurement and verification of conformity to requirements
  - Fact-based decision-making
  - Reduction in variation
  - Use of performance information to foster continuous improvement
  - Effective root-cause analysis and corrective action
  - Definition, measurement, analysis, improvement, and control processes
  - Performance of functions by persons who—
    a. Have sufficient, well-defined responsibility, authority, and organizational freedom to identify and evaluate quality issues and concerns and to initiate, recommend or provide solutions
    b. Are not assigned direct responsibility for ensuring that cost or schedule objectives are met

Managing Quality (2 of 2)

Establishing Quality Competencies

- Management of a comprehensive quality program requires subject matter practitioners. To ensure appropriate internal quality expertise, a skills development plan will be established that defines and develops quality competencies. Quality competencies are defined as those inherent and fundamental quality disciplines that are vital to ensure that customer requirements for products and services are satisfied. At a minimum, the following quality competencies will be considered, as well as any others commensurate with organizational requirements:
  - Quality engineering: The application of mathematical and scientific principles in the analysis of a product's design and manufacturing system to identify, reduce, or manage variation at all life-cycle stages.
  - Product quality management: The application of techniques to ensure acquisition quality system provisions and technical product quality requirements, which are sustained throughout the life cycle of the product.
  - Product verification and validation: The application of techniques to ensure product meets operational needs and product design and performance meet specified requirements.
  - Quality systems management: The management of a formalized system that controls the structure, responsibilities, and procedures, to achieve maximum customer(s) satisfaction at the lowest overall cost to the organization.

The recycled rubber industry is incestuous; much of the sales that occur are among the industry players. This is because rubber recyclers have historically adhered to lower standards and specifications, which are unacceptable in other industries.

The recycled rubber industry must incorporate the highest quality standards from its brethren to ensure that the recycled rubber industry is on par with other evolved industries in the manufacturing sector.

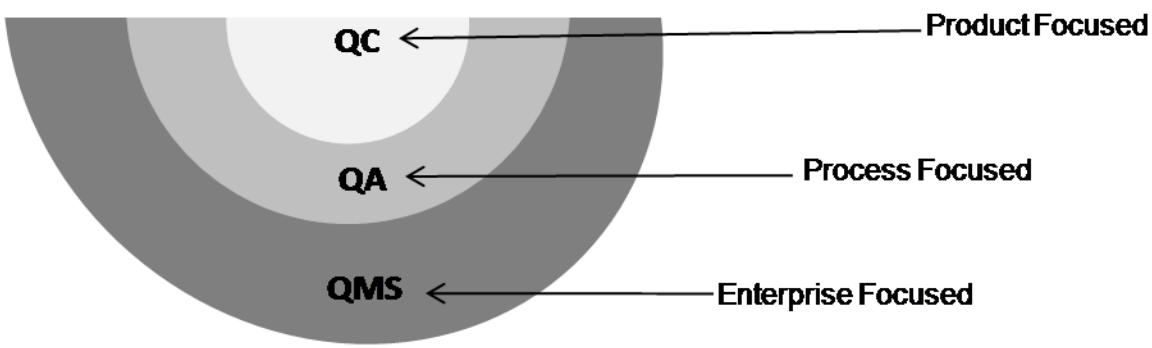
Quality Assurance & Quality Control (QA/QC) (1 of 2)

- What is QA/QC?
  - QA/QC is an act of verifying whether the processes and the work that yield products and services meet the desired quality level and standards
  - There are two key principles that characterize QA:
    - “Fit for purpose" - the product should be suitable for the intended purpose
    - “Right first time" - mistakes should be eliminated
  - QA/QC includes regulation of the quality of raw materials, assemblies, products and components; services related to production; and management, production and inspection processes
  - QA/QC cannot absolutely guarantee the production of *quality* products, but make this more likely
- In QA/QC, acceptable quality requires
  - The establishment of Standards
  - Never passing on “defects”
  - A culture of continuous improvement and problem solving
  - Relentlessly pursuing variability reduction
- Difference between QA & QC
  - Quality assurance (QA) attempts to economically improve and stabilize production, and associated processes, to avoid, or at least minimize, issues that led to the defects in the first place
  - Quality control (QC) emphasizes testing of products to uncover defects, and reporting to management who make the decision to allow or deny the release
- To prevent mistakes from arising, several QA methodologies are used. However, QA does not necessarily eliminate the need for QC: some product parameters are so critical that testing is still necessary
- QC activities are treated as an integral part of the overall QA process

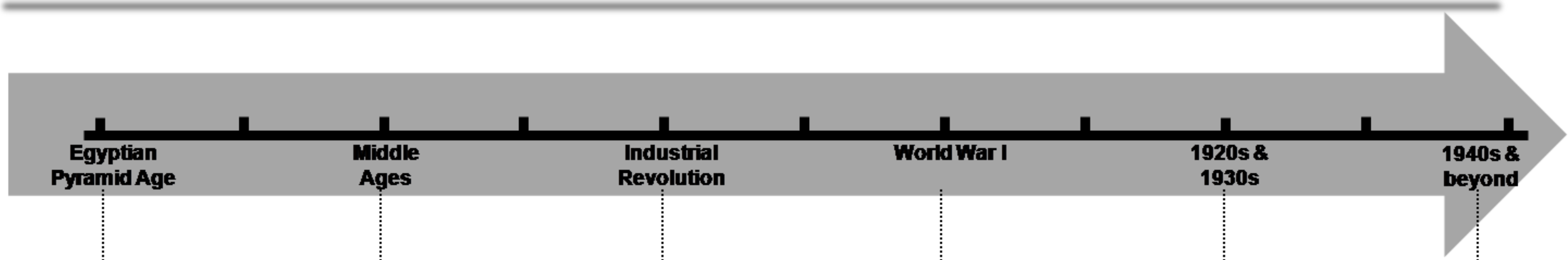
Primary Goal of QA/QC = Building Quality into the Process → ***Good Quality Product***

Quality Assurance & Quality Control (QA/QC) (2 of 2)

- Basic Principles of QA/QC
  - Quality is achieved throughout the life-cycle of a process, NOT just in one or two steps, or in testing.
  - This means that QM/QA/QC should be a consideration in the design and adoption of processes, not just in their testing.
  - Like a system of ethics, QM/QA/QC should pervade the institution.
  - QA/QC is everybody's responsibility, not just the CEO, President, Plant Manager or quality assurance manager. All employees should be reminded of this regularly!
- How does QA/QC fit in the entire Quality Management System?
  - Quality Management System (QMS) is a set of principles, guidelines, and methods by which managers operate a business or institution, in order to be ethical, efficient, meet regulations, and provide a quality product.
  - Quality Assurance (QA) is a set of operating principles, strategies and methods which assure that the technological processes in place are ethical, efficient, meet regulations, and provide a quality product. The emphasis is on process.
  - Quality Control (QC) is a set of processes put in place to guarantee the accuracy of data or the quality of the product. The emphasis is on product.



QA/QC: Historical Perspective – The Timeline (1 of 2)



Early civil engineering projects needed to be built from specifications, for example the four sides of the base of the Great Pyramid of Giza were required to be perpendicular to within 3.5 arc seconds.

During the Middle Ages, guilds adopted responsibility for quality control of their members, setting and maintaining certain standards for guild membership.

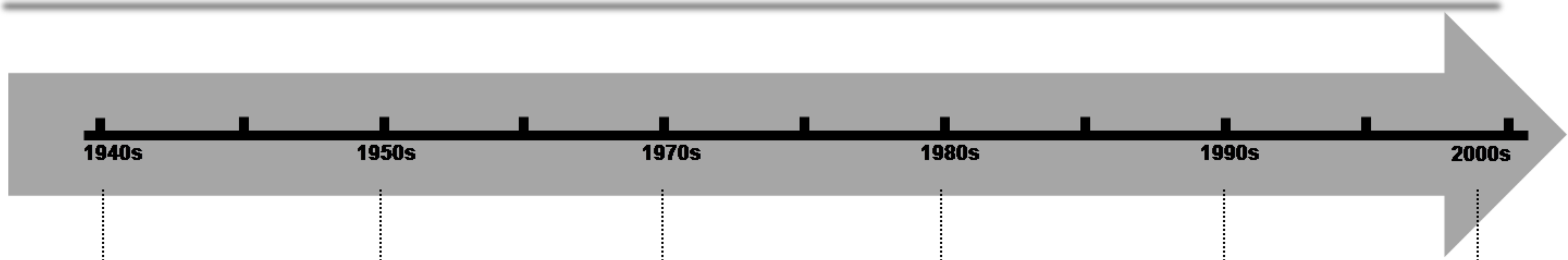
The Industrial Revolution led to a system in which large groups of people performing a similar type of work were grouped together under the supervision of a foreman who was appointed to control the quality of work manufactured.

Around the time of World War I, manufacturing processes typically became more complex and involved widespread application of mass production and piecework. Full time inspectors were introduced into the factory to identify, quarantine and ideally correct product quality failures.

Quality control by inspection in the 1920s and 1930s led to the growth of quality inspection functions, separately organized from production and big enough to be headed by superintendents.

The systematic approach to quality started in industrial manufacturing during the 1940s, mostly in the USA, when some attention was given to the cost of scrap and rework. With the impact of mass production, which was required during the Second World War, it became necessary to introduce a more appropriate form of quality control which can be identified as Statistical Quality Control or SQC.

QA/QC: Historical Perspective – The Timeline (2 of 2)



The U.S. Military, dependent upon product quality and consistency to support the war effort, becomes the primary proponent of quality. Inspection and sampling techniques are implemented and improved upon, and processes redesigned to increase production efficiency. Statistical quality control is an emerging quality approach.

Following World War II, the quality revolution in Japan spurs the birth of total quality in the United States. The Japanese welcome the input of Americans Joseph M. Juran and W. Edwards Deming, and rather than concentrating on inspection, focus on improving all organizational processes at the worker level. Juran facilitates the move from statistical quality control (SQC) to total quality control (TQC) in Japan.

Japan's high quality products steadily erode market share from U.S. industries. The U.S. response, emphasizing not only statistics but approaches that embraced the entire organization, becomes known as total quality management (TQM).

Six Sigma begins in 1986 as a statistically-based method to reduce defects in production processes at Motorola Inc. By the late 80s, it extends to critical business processes.

In 1991 Motorola certifies its first 'Black Belt' Six Sigma experts, signifying the formalization of the accredited training of Six Sigma methods. In the same year, Allied Signal becomes the second to adopt Six Sigma, followed by GE in 1995.

New quality systems evolve from the foundations of Deming, Juran and the early Japanese practitioners of quality. Quality moves beyond manufacturing into service, healthcare, education and government sectors.

Quality Assurance vs. Quality Control

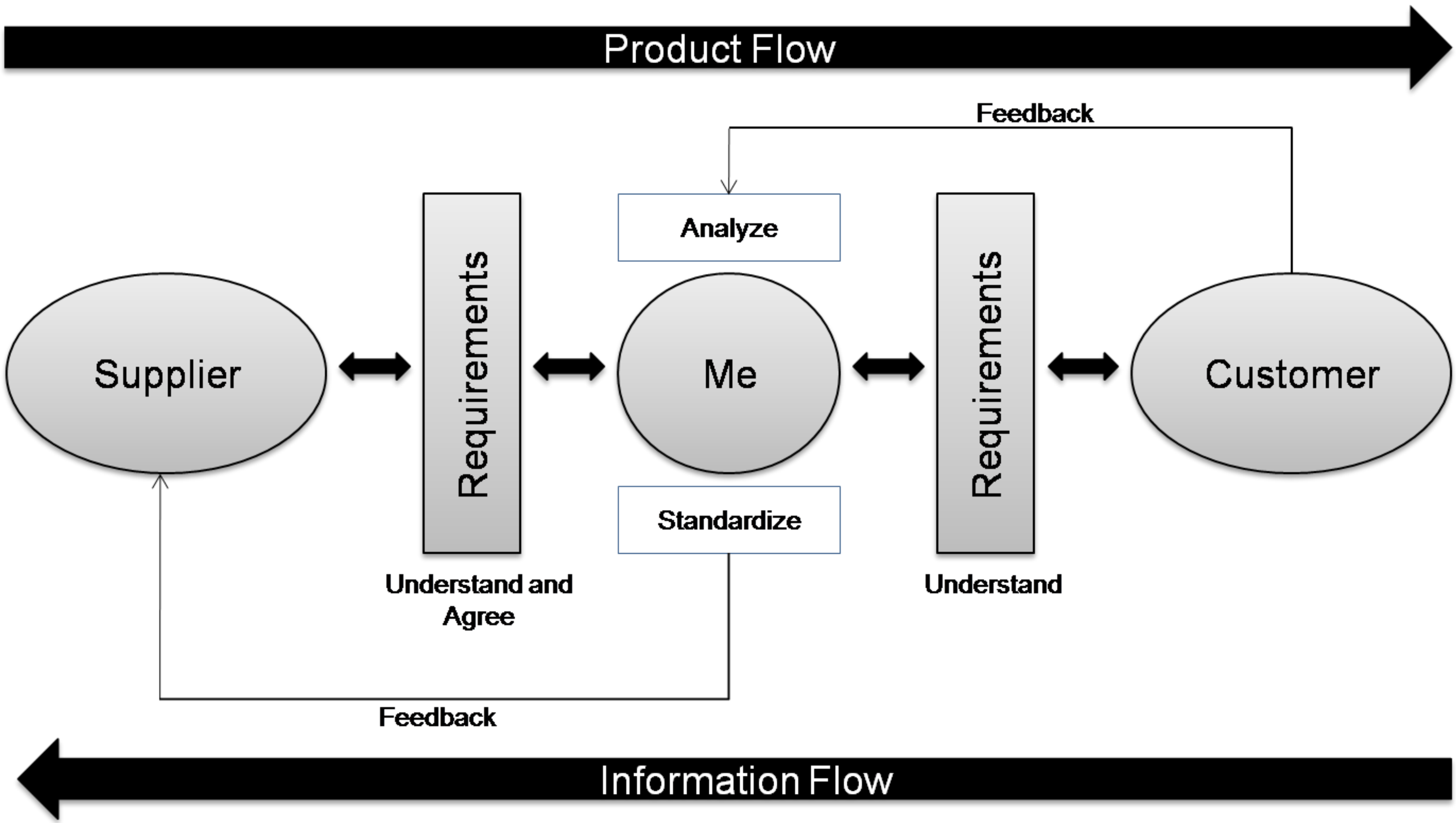
Quality Assurance

- Quality Assurance is the set of all those planned or systematic actions necessary to provide adequate confidence that a product or service will satisfy given requirements for quality.
- Note: Quality Assurance involves making sure that quality is what it should be. This includes a continuing evaluation of adequacy and effectiveness with a view to having timely corrective measures and feedback initiated where necessary. For a specific product or service, Quality Assurance involves the necessary plans and actions to provide confidence through verifications, audit and the evaluation of the quality factors that affect the adequacy of the design for intended applications, specifications, production, installation, inspection and use of the product or service. Providing assurance may involve providing evidence.
- All the planned and systematic activities implemented within the quality system, and demonstrated as needed, to provide adequate confidence that an entity will fulfill requirements for quality. All those planned and systematic actions necessary to provide adequate confidence that a structure, system or component will perform satisfactorily in service.

Quality Control

- Quality Control is the set of operational techniques and activities used to fulfill requirements of quality.
- Note: The aim of Quality control is to provide quality that is satisfactory (e.g., safe, adequate, dependable and economical). The overall system involves integrating the quality aspects of several related steps including the proper specification of what is wanted; design of the product or service to meet the requirements; production or instalation to meet the full intent of the specification; inspection to determine whether the resulting product or service conforms to the applicable specifications; and, review the usage to provide the revision of specification. Effective utilization of these technologies and activities is an essential element in the economic control of quality.

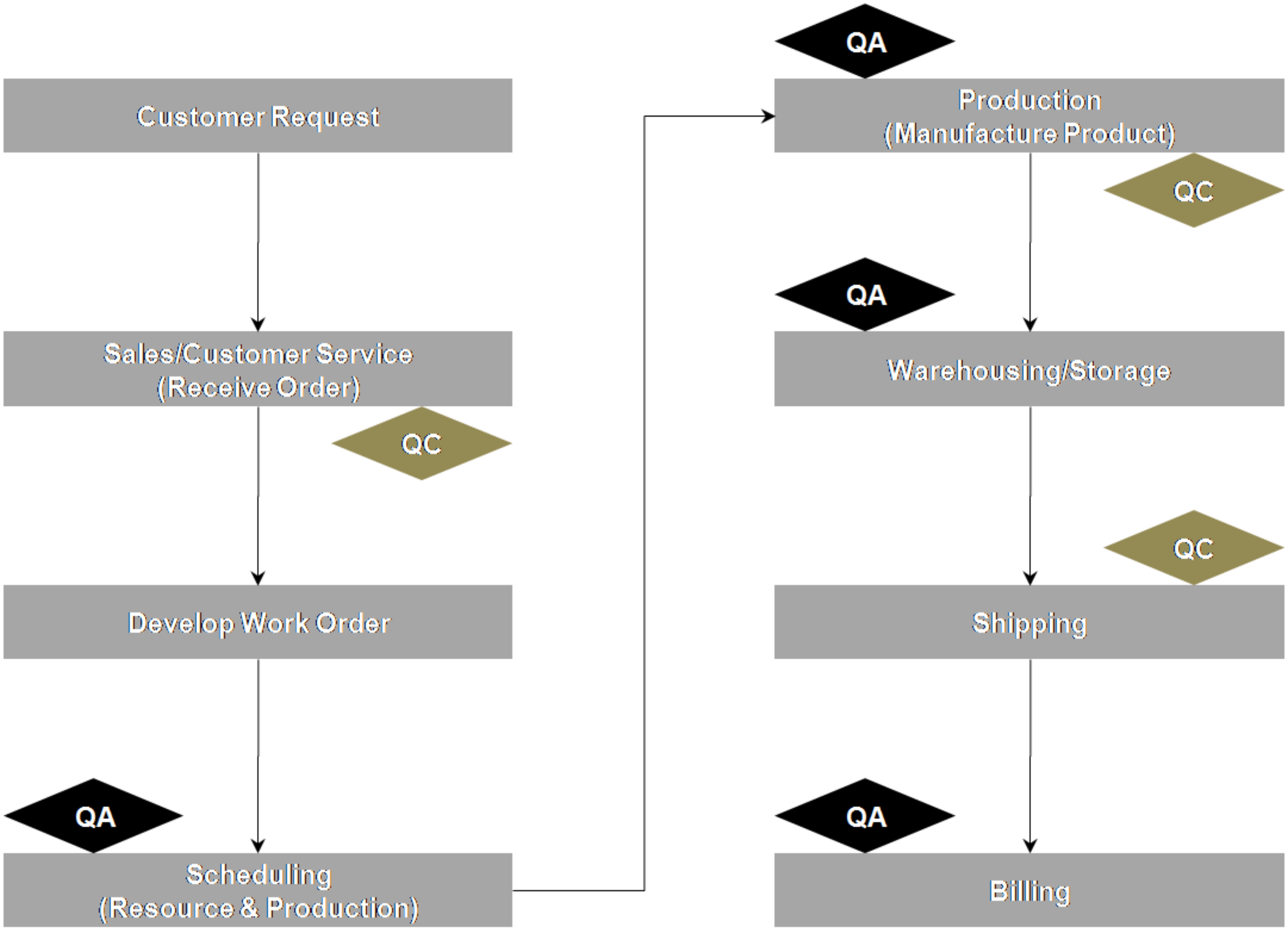
Holistic Perspective to QA/QC



QA /QC Implementation Approach

What is being addressed	Start	Tools used
Realization – I need to improve. What do I need to improve or be better at?	Collect information on problems you may have been facing for the past six months	Customer complaints, Surveys, Internal data, Customer Service feedback, Warranty & repair data, Returns data, Field reports, Observations, Yield etc.
Where am I? What is my current situation?	Analyze the data	Histogram, Scatter diagram, DPMO, 80-20 rule, Brainstorming, Tally charts, Fishbone diagram, 5 Why, Affinity Diagram, ROI etc.
Am I getting better or getting worse over time? What is value-added?	Perform trend analysis	Gap analysis, Waste analysis, Root Cause analysis, Regression, Correlation, Trend lines, Run charts, Pareto analysis, Seasonality etc.
What do my customers want? What is required of me?	Investigate requirements	Voice of customer, Operational work analysis, Benchmarking, Value Stream analysis, Focus groups, Regulations, Standards, Contract review etc.
What are my targets? Where do I want to be? Where do I need to be?	Set goals and establish metrics	SMART goals (Specific, Measurable, Attainable, Relevant, Time-bound), KPI, X-Matrix, Balanced Scorecard, Customer letters and suggestions etc.
How do I build Quality into my processes?	Develop and Implement Quality Assurance Plan	Work procedures, Work instructions, Standard Work, Poka-Yoke/Mistake Proof, Best Practices, Supplier metrics, Engineering Change Notice etc.
How do I make sure I have a quality product?	Develop and Implement Quality Control Plan	Control charts, Statistical Process Control, Sampling & Inspection, Product testing and Validation, Audits, Multi-Vari charts, etc.
	End	

Deploying QA and QC Practices



Sample QA Template

1.0 **General Information**
- 1.1 Purpose
- 1.2 Scope
- 1.3 System Overview
- 1.4 Project References
- 1.5 Acronyms and Abbreviations
- 1.6 Points of Contact
  - 1.6.1 Information
  - 1.6.2 Coordination

2.0 **Schedule of Tasks and Responsibilities**

3.0 **System Documentation**
- 3.1 Documents by Phase
  - 3.1.1 Initiate Phase
  - 3.1.2 Define Phase
  - 3.1.3 Design Phase
  - 3.1.4 Build Phase
  - 3.1.5 Evaluate Phase
  - 3.1.6 Operate Phase
- 3.2 Discipline for Documentation Standard Practices

4.0 **Reviews and Audits**
- 4.1 Review Process
- 4.2 Formal Reviews and Audits
- 4.3 Informal Reviews
- 4.4 Review Reports
- 4.5 Review and Audit Metrics

5.0 **Validation**

6.0 **Problem Reporting and Corrective Action**
- 6.1 Problem/Issue Documentation
- 6.2 Report Metrics

7.0 **Tools and Techniques**

8.0 **Project Controls**
- 8.1 Product Control
- 8.2 Supplier Control

9.0 **Training**

1.0 General Information

1.1 **Purpose:** Describe the purpose of the Quality Assurance Plan.

1.2 **Scope:** Describe the scope of the Quality Assurance Plan as it relates to the project.

1.3 **System Overview:** Provide a brief system overview description as a point of reference for the remainder of the document, including responsible organization, system name or title, system code, system category, operational status, and system environment and special conditions.

1.4 **Project References:** Provide a list of the references that were used in preparation of this document.

1.5 **Acronyms and Abbreviations:** Provide a list of the acronyms and abbreviations used in this document and the meaning of each.

1.6 **Points of Contact:**

1.6.1 **Information:** Provide a list of the points of organizational contact (POCs) that may be needed by the document user for informational and troubleshooting purposes.

1.6.2 **Coordination:** Provide a list of organizations that require coordination between the project and its specific support function (e.g., Resource scheduling, Production, Planned maintenance, etc.). Include a schedule for coordination activities.

Sample QA Plan (2 of 6)

2.0 Schedule of Tasks and Responsibilities

Based on the tasks described in your Project Plan, provide a schedule of the QA activities for the duration of the project. Tasks may include, but are not limited to, those listed below:

- Identify Standards, Specifications and Guidelines
- Evaluate operator skill level
- Evaluate machine capability and capacity
- Evaluate inventory availability
- Evaluate supplier participation and schedule
- Evaluate Production Tools
- Evaluate Facilities
- Evaluate Products Review Process
- Evaluate Project Planning, Tracking, and Oversight Processes
- Evaluate Requirements Analysis Process
- Evaluate Design Process
- Evaluate Prototype and Unit Testing Process
- Evaluate Prototype Release Process
- Evaluate the Corrective Action Process
- Evaluate Specific Certification Process
- Evaluate Storage and Handling Process
- Evaluate Deviations and Waivers Process
- Evaluate Product Configuration Management Process (Engineering/Design Changes)
- Perform Product Configuration Audits
- Evaluate Risk Management Process
- Evaluate occurrences of planned maintenance schedule

Sample QA Plan (3 of 6)

<u>3.0 System Documentation</u>

3.1 **Documents by Phase:** List and briefly describe the documentation expected to be produced. Depending on the size of your project, this may include, but is not limited to, the documents in the following subsections:

3.1.1 **Initiate Phase:**

- Needs Statement (what customer wants)
- Project Plan (including WBS)
- Product Design/Configuration Management Plan
- Cost/Benefit Analysis
- Risk Analysis

3.1.2 **Define Phase:**

- Functional Requirements Document
- Data Requirements Document (Product Features)
- Internal Audit Plan
- Project Plan (updated)

3.1.3 **Design Phase:**

- System/Subsystem Specifications
- Validation, Verification, and Testing Plan (initial)
- Training Plan (initial)
- Project Plan (updated)

<u>3.0 System Documentation</u> (continued….)

3.1.4 **Build Phase:**

- Installation and Conversion Plan (initial)
- Test Plan
- User's Manual
- Operations Manual
- Maintenance Manual
- Validation, Verification, and Testing Plan (final)
- Training Plan (final)
- Project Plan (updated)

3.1.5 **Evaluate Phase:**

- Test Results and Evaluation Reports
- Installation and Conversion Plan (final)
- Project Plan (updated)

3.1.6 **Operate Phase:**

- Pilot Test Results
- Training Material
- Project Plan (updated)

3.2 **Discipline for Documentation Standard Practices:** Describe the criteria that will be applied during review and evaluation of all lifecycle documents.

Sample QA Plan (5 of 6)

4.0 Reviews and Audits

4.1 **Review Process:** Define the steps of the review process and the procedures that will be used to conduct reviews

4.2 **Formal Reviews and Audits:** Typically these reviews include the following, but are not limited to these subsections:

- Requirements review
- Product specification review
- Preliminary design review
- Critical design review
- Prototype readiness review
- Production readiness review
- Acceptance test review
- Post-production review

4.3 **Informal Reviews:** Outline the types of informal reviews that will be conducted

4.4 **Review Reports:** Identify QA reports that will be produced

4.5 **Review and Audit Metrics:** Define and describe the metrics that will be used to capture KPI (key performance indicator) and how they will be analyzed and reported

Sample QA Plan (6 of 6)

5.0 Validation
Identify the roles and responsibilities of the QA function in relation to the validating product parameters as it relates to standards, specifications and customer requirements.

6.0 Problem Reporting and Corrective Action
Discuss QA responsibilities and activities concerned with the reporting and tracking of problems and resolutions.

6.1 **Problem/Issue Documentation:** Explain how problems and issues will be documented and tracked.

6.2 **Report Metrics:** Describe how metrics from the above reports/documents will be collected and analyzed to determine and coordinate corrective actions and develop preventive actions.

7.0 Tools and Techniques
Describe the tools that will be used for QA and the methodology employed to implement the usage of the mentioned tools and techniques.

8.0 Project Controls

8.1 **Product Control:** Identify how QA will monitor the method and tools used to maintain and store products.

8.2 **Supplier Control:** Describe the provisions for assuring that products provided by suppliers meet established requirements.

9.0 Training
Identify the training activities that will be provided to meet the needs of QA.

Sample QC Plan Template

1.0 Choose Control Subject (i.e. what needs to be controlled/regulated)

2.0 Choose a Unit of Measure

3.0 Set a Goal /Target for Control Subject

4.0 Create a Sensor/Measurement device or entity that can measure the control subject in terms of unit measure

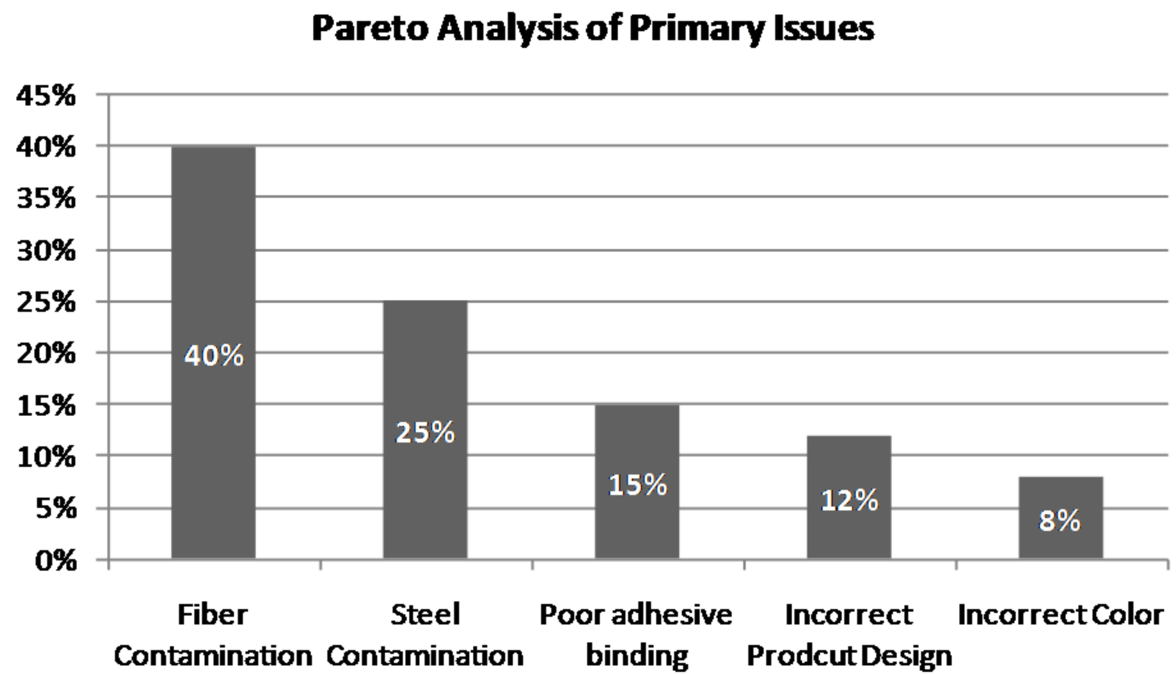
5.0 Measure Actual Performance

6.0 Interpret the Difference between Actual Performance and the Goal

7.0 Take required action on the Difference (if any)

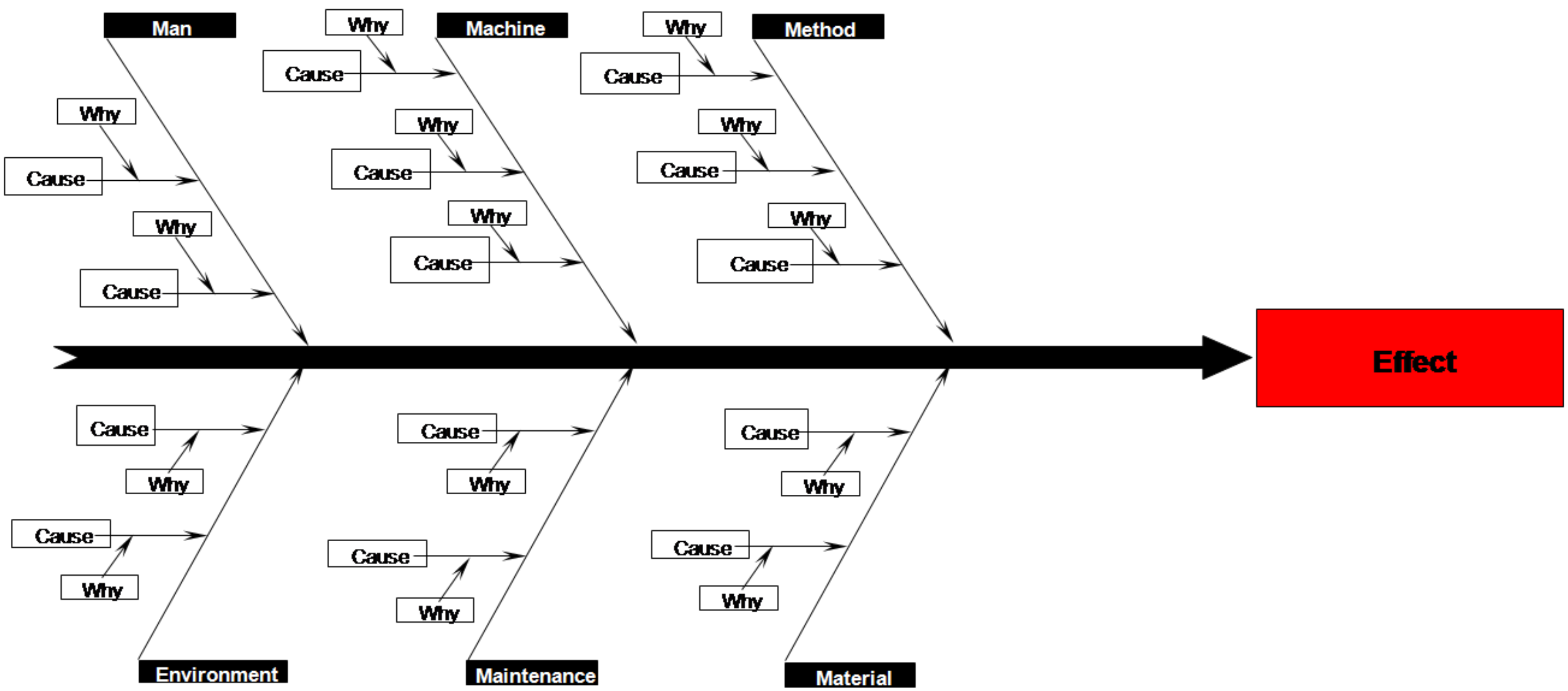
Pareto Analysis

Pareto Analysis is a bar chart that displays by frequency, in descending order, the most important defects or issues. Pareto is an excellent tool to identify critical issues and thereby prioritize their resolutions. The Pareto chart can be used in conjunction with a Cause-Effect diagram (see next tool) or can be used as a stand alone tool. Typically, a 5WHY is used after critical issues have been identified using Pareto Analysis.



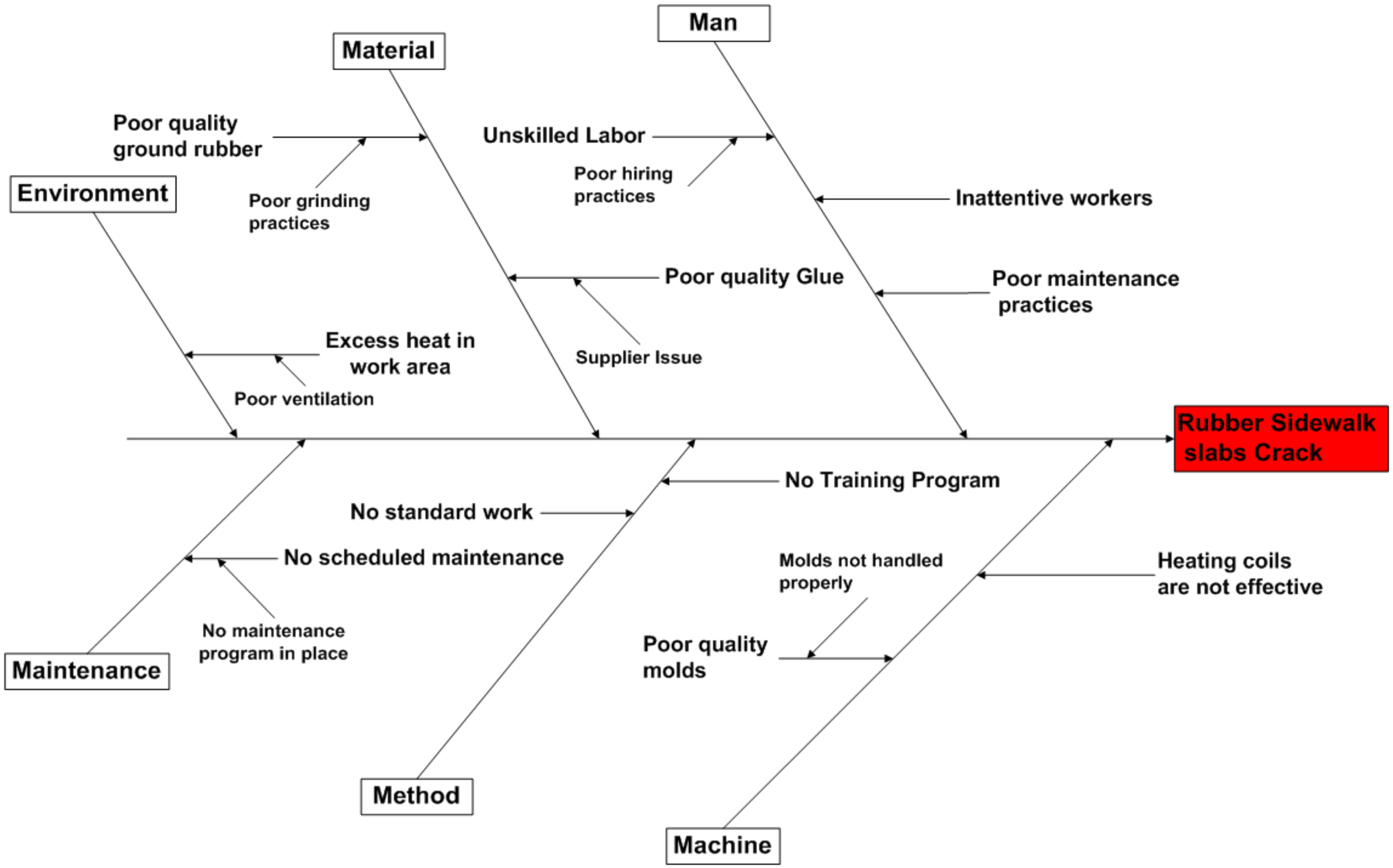
Fish Bone Diagram/Cause-Effect Diagram

The Cause-Effect diagram is one of the most effective tools used during problem solving. This tool is used to identify potential causes of an issue/problem (listed as ‘Effect’ in the red box). The issues can be grouped into six categories – Man, Machine, Method, Material, Maintenance and Environment. Ideally, a team of 2 to 6 people participate in this activity and identify potential causes and in some cases, root causes of a particular issue. A completed chart is then used to develop corrective actions and preventive actions. This chart is sometimes also used to develop a project plan and prioritize the implementation activities in short-term, mid-term and long-term. Typically, use of a tool called 5WHY is practiced after using the Fish Bone Diagram.



Fish Bone Diagram/Cause-Effect Diagram

The following real-life example demonstrates the use of the Fish-Bone diagram to identify the primary causes of crack in rubber sidewalks, after the sidewalks were installed.



Common QA/QC Tools (4 of 6)

5WHY

"5 WHY" is a method to pursue the deeper, systematic causes of a problem and eventually allows you to develop a corresponding deeper countermeasure. This is a problem solving tool that leads employees to the root cause of a problem, by asking "WHY" 5 times.

How 5WHY works:
- State the problem, ask "Why," uncover the cause and continue to ask "Why"
- If you don't get to the root cause, you will be treating only the symptoms

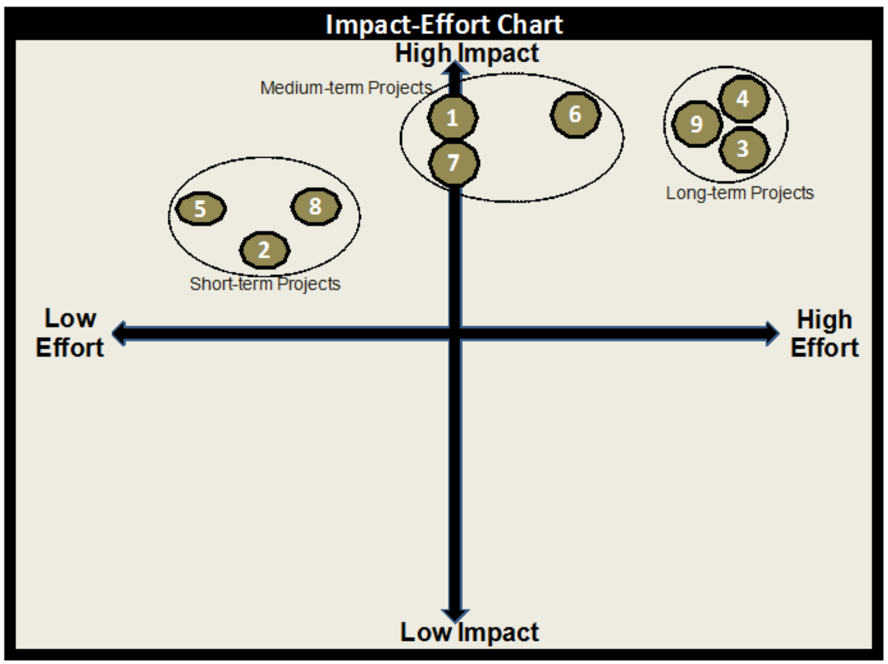
<u>Benefits</u>

- Help identify the root cause of a problem
- Determine the relationship between different root causes of a problem
- One of the simplest tools; easy to complete without statistical analysis
- 5Why is extremely useful when problems involve human factors or interactions

Level	Problem	Level of Countermeasure
1st Why?	There is oil on the shop floor	Clean up the oil
2nd Why?	Because the machine is leaking	Fix the machine
3rd Why?	Because the gasket is bad	Replace the gasket
4th Why?	Because we got a good deal (price).....	Change gasket specifications
5th Why?	Because purchasing is evaluated on short term cost saving	•Change purchasing policies •Change the evaluation policy

Impact-Effort Chart

The Impact-Effort chart is used to prioritize the order in which the issues should be addressed or the order in which the corrective actions should be implemented. The y-axis (Impact) relates to the impact that resolution to a particular issue might have. The x-axis represents the effort needed to implement the resolution. An example of the Impact-Effort chart is shown below. The table beside the chart lists the issues identified for a real-life problem. The numbers on the chart pertain to the corresponding issues in the table. Generally, the Impact-Effort chart is used after a team has completed the brainstorming activity and has identified the issues to be addressed.



Issue Code	Issue
1	Staff not available for rush shipments
2	Guesswork: Sales not aware of actual build time
3	Workflow and order status not evident; hard to track progress
4	Lack of better dashboards & reports
5	Poor quality stock from suppliers
6	Not getting needed parts from suppliers on time
7	Part delivery must always be checked thru' James
8	Sales department doesn't know the actual customer demands
9	Softwares are not upgraded

Roadmap

A Roadmap is a simple project plan that is used after the Impact-Effort chart has been developed. The Roadmap has a list of the project/issues (Refer to Issue Code) that need to be addressed, a start date and end date of that project, metrics used to measure the progress and names of the team members involved in the project. An example of a real-life Roadmap is shown below.

Roadmap

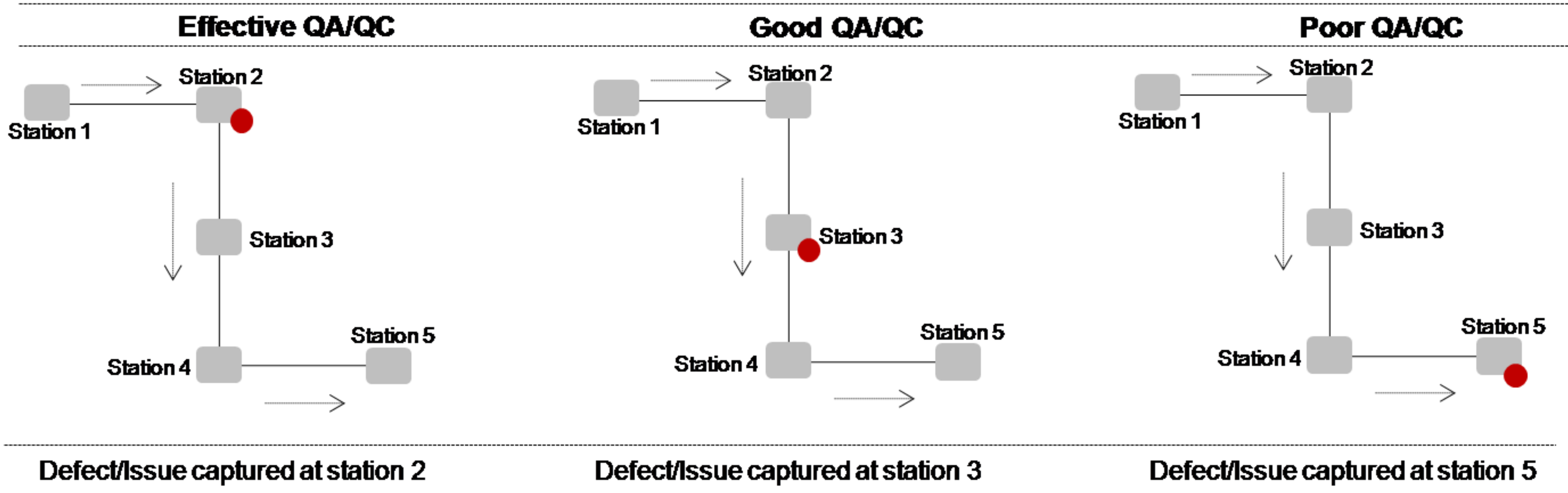
Term	Issue Code	Responsible Person (s)	When		Metrics
			Start Date	End Date	
SHORT	1	Al, Jodie	12/9/2009	1/23/2010	* Number of data points * Accuracy if data points (%)
	6	Al, Brian W, Dave L, Issac T	11/5/2009	11/28/2009	* Cost of change ($)
MEDIUM	2 & 4	Al, Joey, Skip	12/15/2009	2/20/2010	*Accuracy (%)
	3	Issac, Ed G	1/4/2010	3/4/2010	* Job release accuracy (%) * OTD from supplier (%)
LONG	5	Lesley, Dave L, Gina	2/5/2010	6/1/2010	* Planned resource utilization (%) * OTD/Completion of discrete operations/job (%)

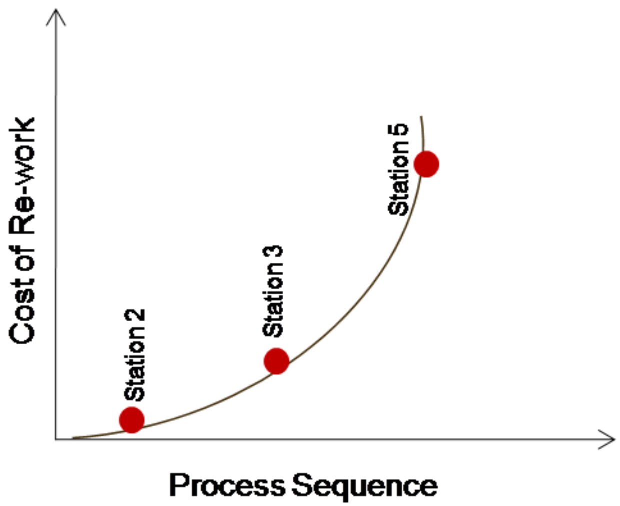
Benefits of Effective QA/QC Practices (1 of 2)

- Primary Benefits
  - Customer satisfaction
  - Good PR/credibility
  - Repeat business and new business
  - Entry into new markets
  - Entry into markets that use products made out of virgin rubber
  - Increased product life
  - Significant reduction in defects, scrap and rework
  - Reduction in product cycle time and overall lead time
  - Increase in on-time delivery
  - Substantial cost savings
  - Increased profitability
  - Standardizes, organizes and controls operations
  - Socially responsible - helping the environment

- Other Benefits
  - Improved consistency of service and product performance
  - Improved customer perception
  - Improved productivity and efficiency
  - Alignment of the company's current QMS with industry standards
  - Improved communications, morale and job satisfaction
  - Competitive advantage and increased marketing and sales opportunities
  - International acceptance and recognition
  - Facilitated trade in international markets
  - Promotion of safety, reliability and quality in food products
  - Provides for consistent dissemination of information
  - Improves various aspects of the business based on use of statistical data and analysis
  - Acceptance of the system as a standard for ensuring quality in a global market
  - Enhances customer responsiveness to products and service
  - Encourages continuous improvement

Benefits of Effective QA/QC Practices (2 of 2)

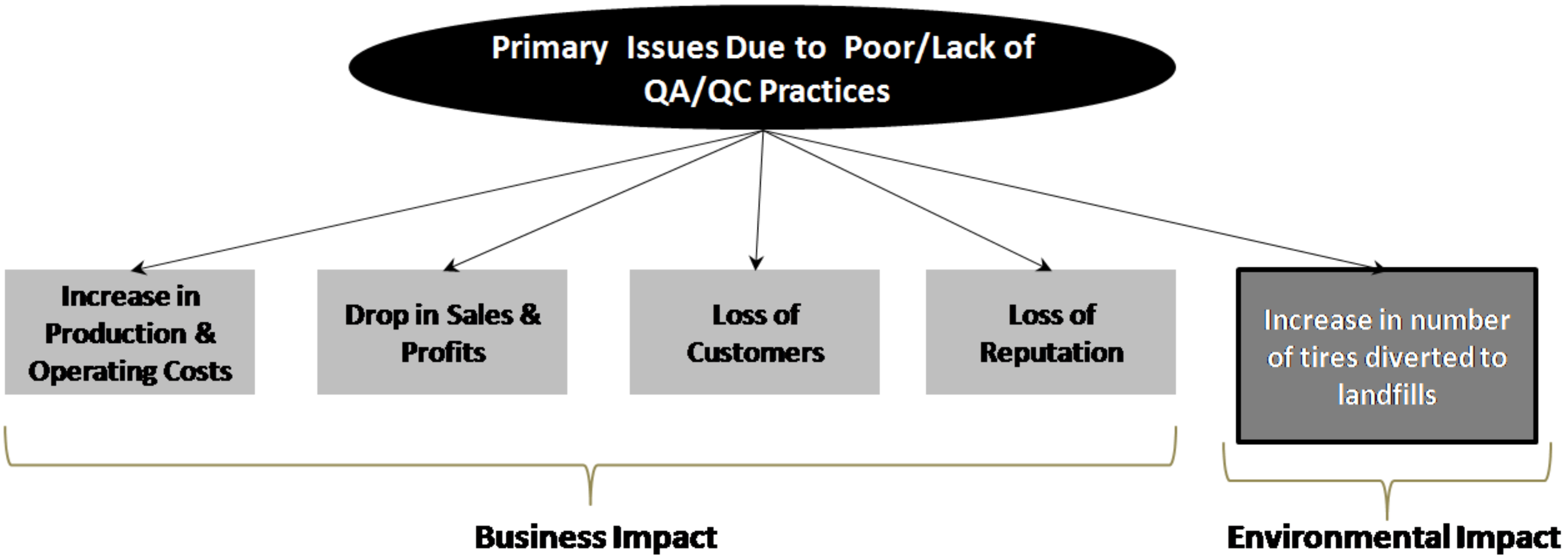




The cost incurred due to detection of an issue or a defect increases exponentially, as the point of detection of an issue or a defect moves downstream into the process sequence.

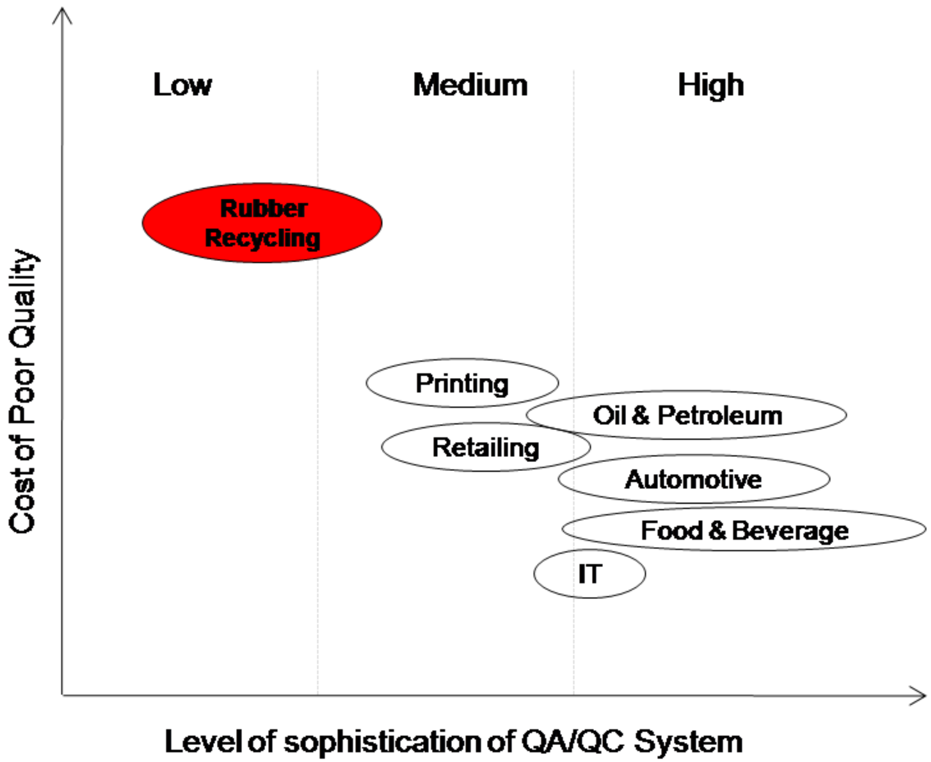
E.g.: Twenty super sacks filled with colored mulch are identified to have steel contamination after inspection, just before being shipped to a customer. The cost incurred to fix the contamination at this stage is exorbitant. As the defect detection moves downstream, costs such as labor, material, electricity, and other overhead costs get added to the job in process. If the contamination was detected after the primary or secondary grinding process, the cost would have been much lower.

- Our research has demonstrated that most of the processors and manufacturers lack a QA plan and do not have QC procedures in place. Most of the activities that these processors carry out lack any pro-activeness and direction. Generally, the day-to-day operations are conducted in 'fire fighting' mode, without addressing the root cause of the issues. Addressing the symptom (a common practice), instead of the root cause leads to the issues resurfacing after some time, and the cycle repeats. This practice generates a lot of internal rework, warranty returns, erosion of final product quality and even safety hazards. The ultimate impediments of such inefficiencies leads to a steep increase in production and operating costs, a drop in sales, loss of customers and erosion of reputation. The other major impact of such impediments is a drop in the number of tires that are processed and converted into a usable form, leading to more tires being diverted to the landfills.



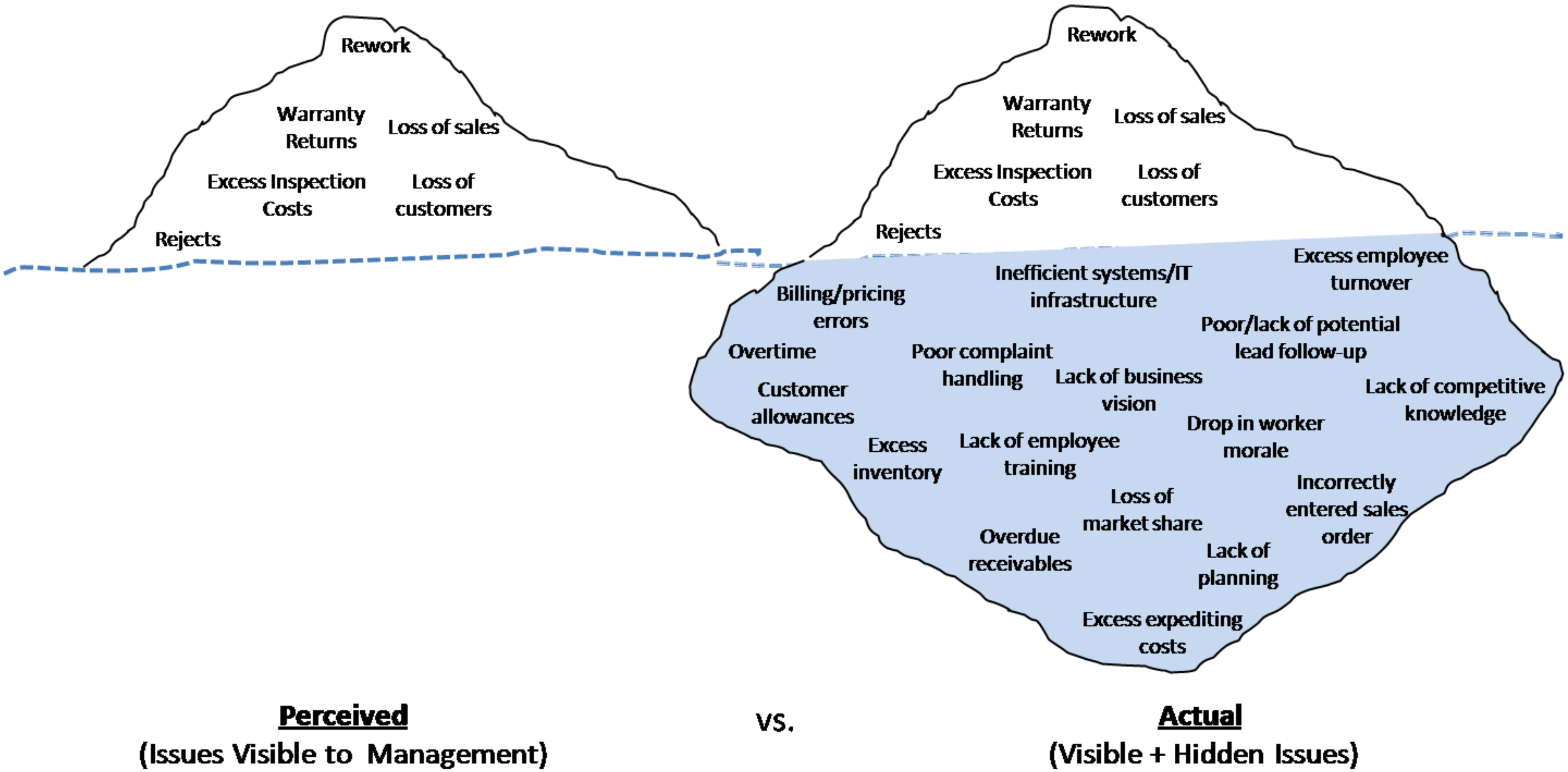
QA/QC Issues For Rubber Recyclers (2 of 3)

- Based on our industry research, we estimate that the rubber recycling industry fares very poorly when compared to other industries. The chart shown below depicts that the rubber recycling industry (primarily the processors and manufacturers) has one of the lowest levels of sophistication when it comes to having a QA/QC system in place. Moreover, costs incurred due to poor quality (per unit basis) are extremely high, compared to other industries. This fact indicates why the number of issues due to either existence of rudimentary QA/QC or lack of QA/QC practices is extremely high for the rubber recycling industry.



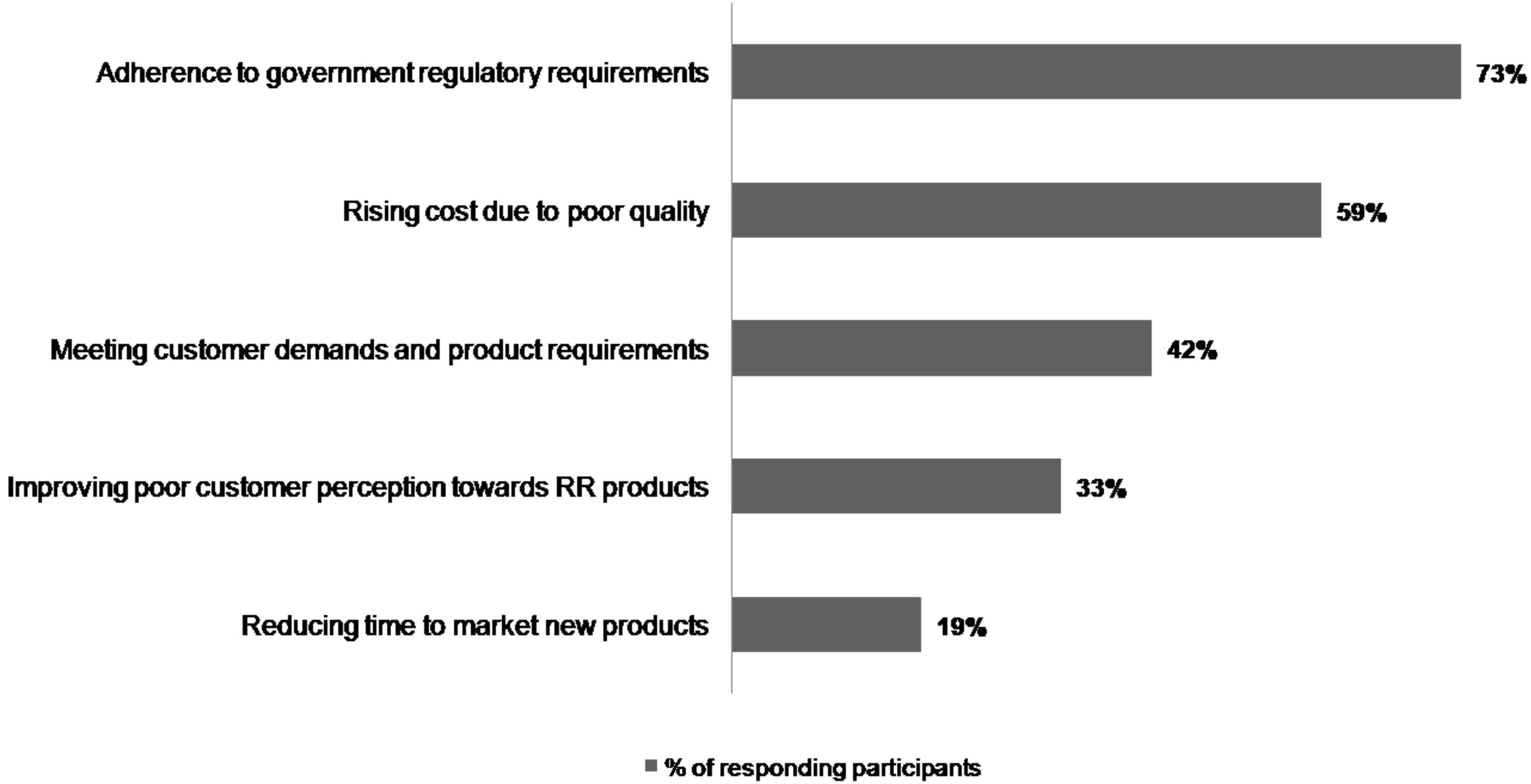
Benchmarking Analysis

- During our research, we found that several businesses believed that they knew all the issues related to their product, process and business. However this belief was far from reality. The Iceberg-model below explains our findings. The issues visible to management lie in the portion of iceberg above the dotted line, while the gamut of issues listed below the dotted line were either rarely visible or not visible at all. One of the primary reasons for such lack of visibility is due to the absence of any quality management plan within these organizations.



Top Issues Faced by Rubber Recyclers

- Our research generated the following chart that represents some of the top issues faced by today's rubber recyclers:



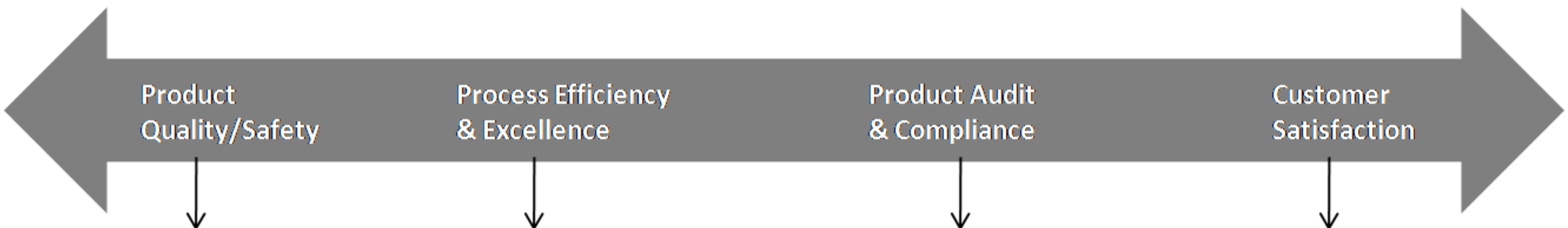
Integrating QA/QC For Better Results

As previously mentioned, generally businesses in the rubber recycling industry are reactive in nature, identifying problems that already have occurred and correcting them. The best practice should be to integrate quality into each step of the value stream. A leading quality body suggests the following two-point plan:

1) integrating quality control into the ongoing production process to catch problems as soon as they occur and

2) refocusing the quality function on proactive identification of potential problem areas.

The businesses within the rubber recycling domain should not only integrate quality into their organizations, but into the entire value chain as a whole. During each phase of the process, specific QA/QC measures should be put in place to enable economical and efficient operation within the entire value chain. The following exhibit represents the performance measures enabling QA/QC integration into an enterprise.



Product Quality/Safety

- Cost of Quality
- First-Pass Yield
- DPMO
- Defects Per Unit
- Error Rate
- Warranty Returns
- Product Reliability
- Unit Failure Rate
- Number of Recalls

Process Efficiency & Excellence

- Installation Cycle Time
- Lead Time
- Process Capability
- Productivity
- Returns Cycle Time
- Process Improvement
- Continuous Improvement
- Productivity Improvement
- Adherence to Takt Time

Product Audit & Compliance

- Process Audit Conformance
- Compliance to GMP
- Regulatory Compliance
- Compliance to Standard Tests and Specifications
- Continuous Improvement of Audit Scores
- ISO/FDA Compliance
- Compliance to ASTM &ADA standards
- Compliance to EPA

Customer Satisfaction

- Customer Rejects
- New Client Growth
- Understand Customer Needs
- Consumer Compliant Reduction
- Meet or Exceed Consumer Requirements
- Client Retention
- Complaints
- Consumer Perception of Quality

Integrating QA/QC for Product Pricing

A good quality product can command a premium price. The following matrix depicts the relationship between the price of a product and the value provided by that product. Rubber Recyclers can use this matrix to categorize their products at various quality levels and for various market segments, based on the price/value relationship. Rubber Recyclers can use this matrix to price discriminate among their products based on the target market and the value offered by the product to the target market. The pricing of the product and the value offered can be regulated by the amount of QA/QC effort administered toward that product.

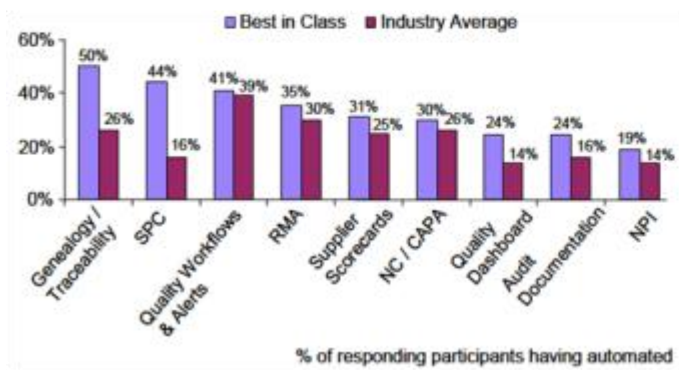
Value Provided \ Price	Low	Medium	High
High	Underpriced	Ideal for Market Penetration	Premium Offering
Medium	Real Bargain	Average	Over Priced
Low	Cheap Goods	Unhappy Customers	Make the sale and run

Practices Adopted by Best-in-Class

Best-in-Class manufacturers use a two-tiered business process strategy. First, Best-in-Class manufacturers establish and standardize quality process workflows and escalation procedures at the corporate level. Second, Best-in-Class manufacturers allow the execution of these quality processes and escalations to be managed at the local departmental level. Such a process structure allows Best-in-Class manufacturers to build workflows based on best practices and continuous improvement principles, while still benefiting from the flexibility attributed to local execution.

Market Pressures Driving the Best-in-Class (Source: Aberdeen Group)

Strategic Actions the Best-in-Class are Taking (Source: Aberdeen Group)



Automated Quality Tools Enabling Best-in-Class Status (Source: Aberdeen Group)

How Best-in-Class Manufacturers are Performing (1 of 2)

Best-in-Class manufacturers use a two-tiered business process strategy. First, Best-in-Class manufacturers establish and standardize quality process workflows and escalation procedures at the corporate level. Second, Best-in-Class manufacturers allow the execution of these quality processes and escalations to be managed at the local departmental level. Such a process structure allows Best-in-Class manufacturers to build workflows based on best practices and continuous improvement principles, while still benefiting from the flexibility attributed to local execution.

Definition of Maturity Class	Mean Class Performance
Best - in - Class: Top 20 % of aggregate performance scorers	▪ 91% First Pass Yield ▪ 95% Overall Yield ▪ 5.05 Sigma – as a measure of DPMO
Industry Average: Middle 50% of aggregate performance scorers	▪ 89% First Pass Yield ▪ 90% overall yield ▪ 3.68 Sigma – as a measure of DPMO
Laggard: Bottom 30% of aggregate performance scorers	▪ 70% First Pass Yield ▪ 70% overall yield ▪ 1.81 Sigma – as a measure of DPMO

How Best-in-Class Manufacturers are Performing (2 of 2)

- The cost of quality for best-in-class companies is 8% or less of total sales
- The first pass yield for best-in-class companies is over 91%
- Best-in-class companies have 98% complete and on-time shipments
- Best-in-class companies meet or exceed customer service expectations over 95% of the time
- Top performing companies operate with less than 45 days of inventory throughout the entire supply chain
- Best-in-class companies have 75% to 95% more asset utilization
- Even delivery and logistics objectives exist; for example, lift trucks should perform 5-1/2 hours of use on an 8 hour shift (68% utilization)

Cost of Quality (1 of 5)

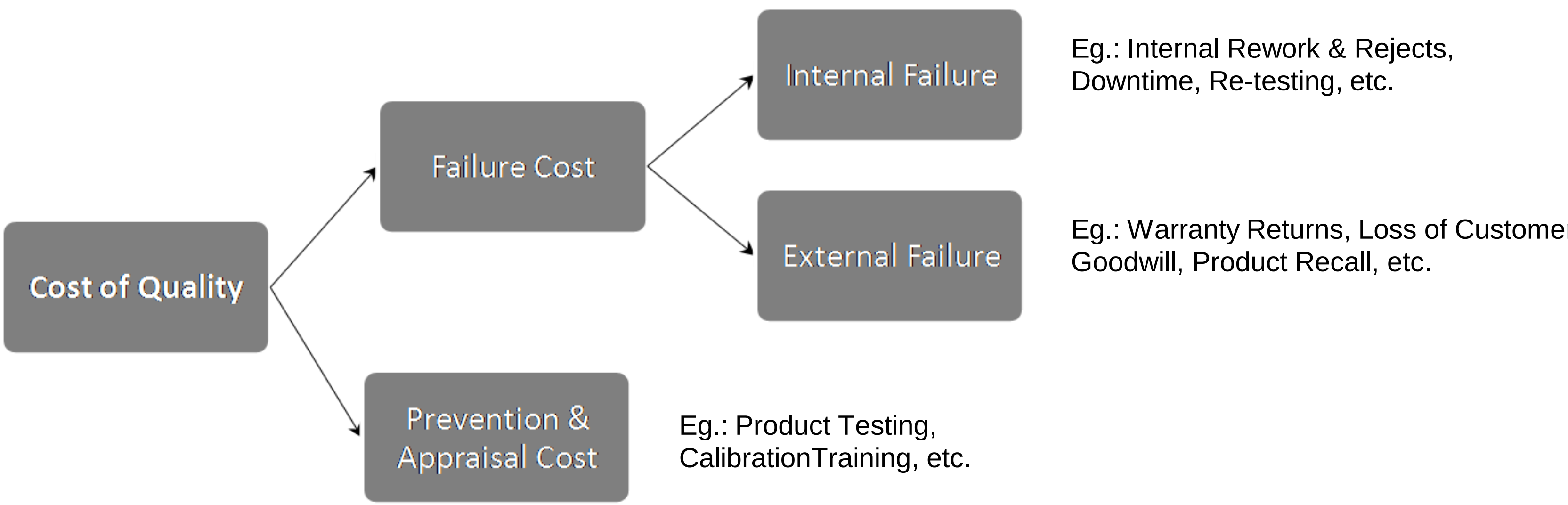
- "A manufacturing company had annual sales of $250 million. Its quality department calculated the total cost of repair, rework, scrap, service calls, warranty claims and write-offs from obsolete finished goods. This aggregated cost, called cost of poor quality (COPQ) amounted to 20% of the annual sales. A 20% COPQ implied that during one day of each five-day workweek, the entire company spent time and effort making scrap, which represented a loss of approximately $200,000 per day." *(Source: www.qualitydigest.com)*

- The "cost of quality" isn't the price of creating a quality product or service. It's the cost of NOT creating a quality product or service. Every time work is redone, the cost of quality increases. Obvious examples include:
  - The reworking of a manufactured item
  - The retesting of an assembly.
  - The rebuilding of a tool
  - The correction of a bank statement
  - The reworking of a service, such as the reprocessing of a loan operation or the replacement of a food order in a restaurant
- Many companies promote quality as the central customer value and consider it to be a critical success factor for achieving competitiveness
- Any serious attempt to improve quality must take into account the costs associated with achieving quality since the objective of continuous improvement programs is not only to meet customer requirements, but also to do it at the lowest cost
- This can only happen by reducing the costs needed to achieve quality, and the reduction of these costs is only possible if they are identified and measured
- Therefore, measuring and reporting the cost of quality (CoQ) and incorporating this practice in the overall QA/QC approach should be considered an important issue for managers

Cost of Quality (2 of 5)

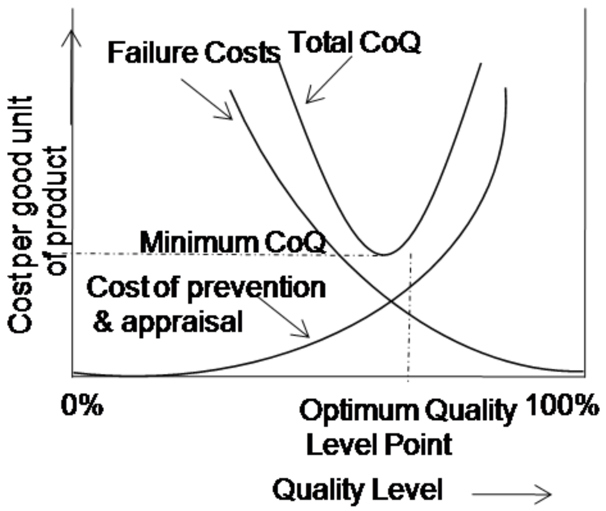
Definition: CoQ is usually understood as the sum of conformance plus nonconformance costs, where cost of conformance is the price paid for prevention of poor quality (for example, inspection and quality appraisal) and cost of nonconformance is the cost of poor quality caused by product and service failure (for example, rework and returns).

- According to Dale and Plunkett (1995), it is now widely accepted that quality costs are: the costs incurred in the design, implementation, operation and maintenance of a quality management system, the cost of resources committed to continuous improvement, the costs of system, product and service failures, and all other necessary costs and non-value added activities required to achieve a quality product or service.
- Companies that have incorporated the Cost of Quality (CoQ) approach in their QA/QC practices have been extremely successful in reducing quality cost and improving quality for their customers.
- There are several CoQ models in practice. Each model is selected based on the situation, the environment, the purpose and the needs of the company.
- The most widely used CoQ model is the "P-A-F" (Prevention-Appraisal-Failure) model.



The PAF model

- The PAF or Prevention-Appraisal-Failure model is based on Armand Feigenbaum's Quality costing analysis and Joseph Juran's Economics of quality model.
- Prevention costs are associated with actions taken to ensure that a process provides quality products and services, appraisal costs are associated with measuring the level of quality attained by the process, and failure costs are incurred to correct quality in products and services before (internal) or after (external) delivery to the customer.
- Juran later highlighted the traditional tradeoff that contrasts prevention plus appraisal costs with failure costs (Juran, 1962). The basic suppositions of the PAF model are that investment in prevention and appraisal activities will reduce failure costs, and that further investment in prevention activities will reduce appraisal costs (Porter and Rayner, 1992; Plunkett and Dale, 1987). The objective of a CoQ system is to find the level of quality that minimizes total cost of quality. Feigenbaum's and Juran's P-A-F scheme has been adopted by the American Society for Quality Control (ASQC, 1970), and the British Standard Institute (BS6143, 1990), and is employed by most of the companies which use quality costing (Porter and Rayner, 1992).
- The above-mentioned classical view of quality cost behavior in the P-A-F model holds that an optimum economic quality exists at the level at which the cost of securing higher quality would exceed the benefits of the improved quality.



Cost of Quality (4 of 5)

Current Practice

- Companies rarely have a realistic idea of how much profit they are losing through poor quality.
- Smaller firms most often do not even have any quality budget and do not attempt to monitor quality costs.
- Large companies usually claim to assess quality costs; however even though most managers claim that quality is their top priority, only a small number of them really measure the results of quality improvement programs.
- Even in companies that do measure results, quality costs are horrendous. Few of the companies claiming that they monitor quality costs have an established framework for the collection across the full range of quality cost categories.
- Moreover, companies measure visible and quantifiable costs such as scrap and warranty, but ignore significant costs such as lost sales due to customer defection.
- A high proportion of the costs have proven difficult to measure and have therefore remained hidden.
- Measuring return on quality is not a common practice. Spending money on quality improvement programs without ever estimating expected benefits, leads to investment with little or no impact on the bottom line.
- Even though quality is now widely acknowledged as a key competitive weapon, it seems that there is a lack of quality vision and commitment among top management.

Cost of Quality (5 of 5)

Cost of Quality (CoQ) measurement should be a part of any quality management program. The methodology is not complex and is well documented. CoQ programs provide a good method for identification and measurement of quality costs, and thus allow targeted action for reducing CoQ. Further education on the practical level is needed for managers to better understand the CoQ concept in order to appreciate fully the benefits of the approach, to increase their ability to implement a CoQ measurement system and to save money. Thus, CoQ should be an integral part of any QA/QC program.

Success Stories

- Raytheon: Raytheon yielded a twofold increase in its productivity and a return ratio of 7.7 to 1 on its improvement expenditures, for a 1990 savings of $4.48 million from a $0.58 million investment. Over a period of four and a half years, from mid-1988 to the end of 1992, the company eliminated $15.8 million in rework costs.
- Tinker Air Force Base computed a 5-to-1 return on investment for its process improvement initiatives, which generated a savings of $3.8 million from a $0.64 million investment.
- ITT: The success of multinational corporation, ITT, that implemented a CoQ system are often cited in literature. Groocock (1980) presents how ITT Europe headquartered in Belgium coped with quality cost control and saved over $150 million during 5 years.
- United Technologies Corporation: United Technologies Corporation, Essex Telecommunication Products Division, established CoQ measurement based on a P-A-F model, and five years of implementation have yielded a productivity improvement of 26%.

Quality Management System (QMS) (1 of 2)

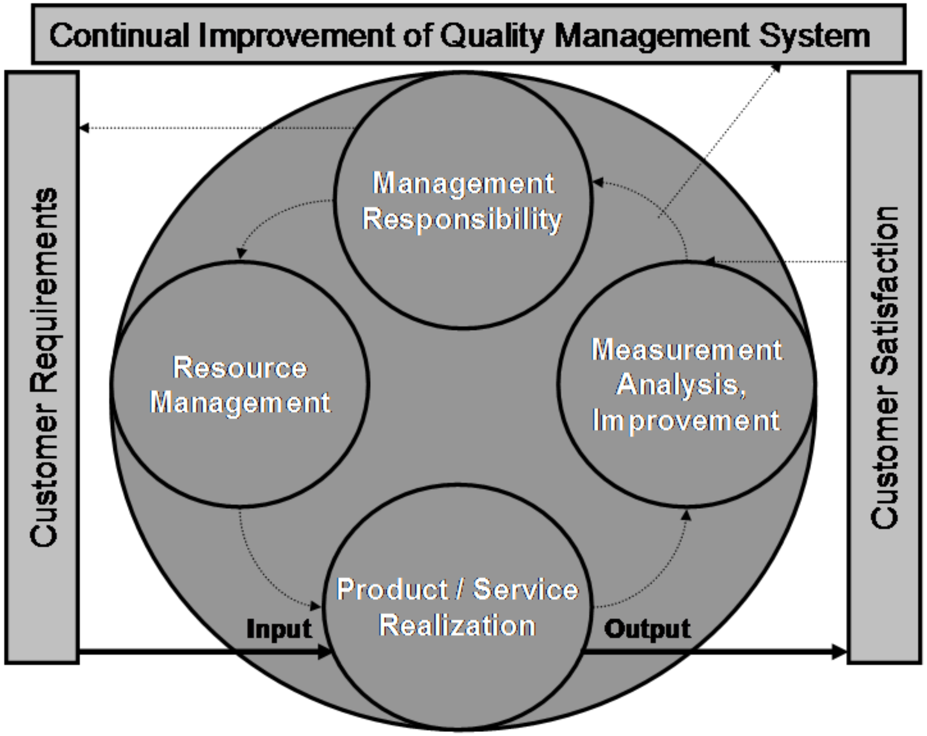
Definition

"A set of coordinated activities to direct and control an organization in order to continually improve the effectiveness and efficiency of its performance."

- An organization will benefit from establishing an effective quality management system (QMS). The cornerstone of a quality organization is the concept of the customer and supplier working together for their mutual benefit. For this to become effective, the customer-supplier interfaces must extend into, and outside of, the organization, beyond the immediate customers and suppliers.
- The set of coordinated activities, as mentioned in the above definition will interact and are affected by being in the system, so the isolation and study of each one in detail will not necessarily lead to an understanding of the system as a whole.
- The main thrust of a QMS is in defining the processes, which will result in the production of quality products and services, rather than in detecting defective products or services after they have been produced.

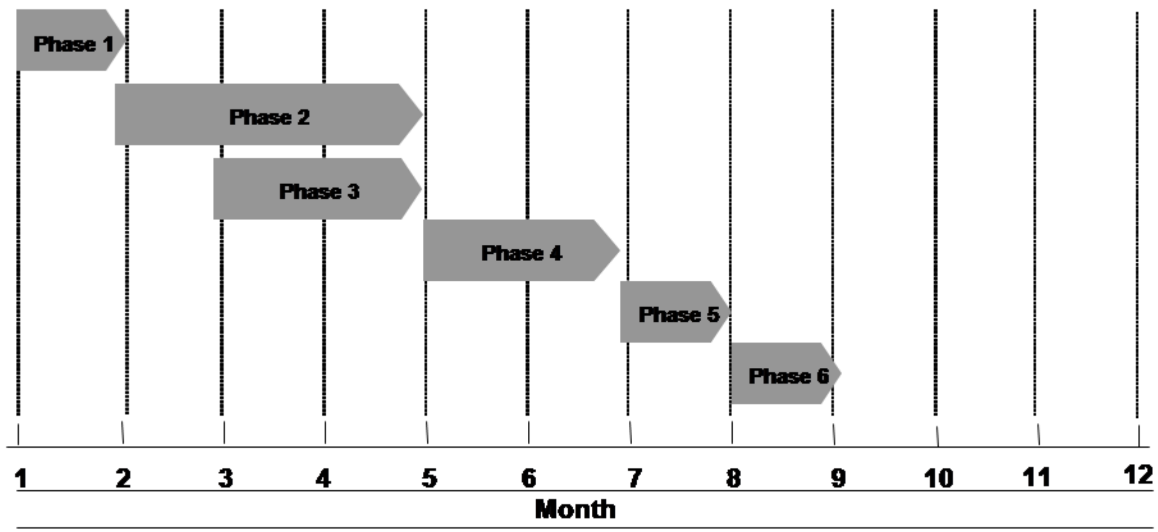
Lack of effective QMS causes over 70% of issues related to quality

- **The advantages of a fully documented QMS are:**
  - The customers' requirements – confidence in the ability of the organization to deliver the desired product and service consistently meeting their needs and expectations
  - The organization's requirements – both internally and externally, and at an optimum cost with efficient use of the available resources – materials, human, technology and information



Fully Documented QMS Model

Example of a QMS Implementation Program



For a small business, it takes on average two employees working part time to deploy an effective QMS in 6 to 9 months.

Phase 1

Step 1: Obtain commitment from top management
Step 2: Establish implementation team
Step 3: Start ISO 9000 awareness programs

Phase 2

Step 4: Provide Training
Step 5. Conduct initial status survey
Step 6. Conduct GAP Analysis

Phase 3

Step 7: Create a documented implementation plan
Step 8: Develop quality management system documentation
Step 9: Document control

Phase 4

Step 10: Implementation
Step 11: Review and Revision

Phase 5

Step 12: Internal quality audit
Step 13: Management review
Step 14: Preassessment audit

Phase 6

Step 15: Certification and Registration
Step 16: Continual Improvement

IV. Common QA/QC Issues Associated with Recycled Rubber Products

- Possibility of experiencing objects and materials that may cause contamination
- This includes both objects that are foreign, as well as materials that are included in the product being recycled that would be objectionable in the final product
- In many instances, various types or grades of rubber may be incompatible when blended together
- Incompatibility can lead to poor processing and performance characteristics
- Incompatibility in the final product results due to poor QA/QC procedures or lack of such procedures
- Incompatibility also causes excess wear and tear of equipment
- Other contaminants of concern in tire, hose, and belt recycling and grinding are the textile and steel reinforcing members
- The steel is removed using a powerful magnetic separator while the fiber is removed using air cyclone separation during processing
- Small amounts of fiber are often found in large particle size whole ground tire. On the other hand, cryogenic grinding is especially effective at removing fiber and steel from the recycled rubber
- One item that the recycler of rubber has to be aware of is to avoid incorporating specialty elastomers containing peroxides and halogens into general purpose polymers
- Many hoses, belts, roofing materials, and O-rings contain specialty elastomers that will be less than compatible
- These materials should only be co-mingled with themselves. The small amount of halogen in the inner liner of tubeless tires is not a problem and it is easily ground and incorporated into whole ground tire recyclate
- EPDM, butyl, and nitrile rubber should also be avoided for blending into ground tire recyclates

Common Practices with QA/QC Issues within Rubber Recycling Industry

Common Practices

1. Storage quality
2. Flammability
3. Sampling procedures
4. Sampling and testing QA plans
5. Cryogenic processing
6. Ambient vs. cryogenic grinding
7. Crumb sizing
8. Bulk density
9. Devulcanization – chemical
10. Devulcanization – microwave
11. Devulcanization – ultrasound
12. Additives for surface modification
13. Extrusion
14. Hot Molding
15. Cold Molding
16. Moisture retention/absorption
17. Contaminates – incompatible rubber polymers
18. Contaminates – fiber & steel
19. Fillers – recycled crumb rubber
20. Recycled rubber content effects on properties of virgin compounds
21. Fillers for rubber components – carbon black
22. Fillers for rubber components – non - black
23. Curing agents and accelerators
24. Binders, bonding agents and adhesives
25. Softeners, oil and plasticizers
26. Rubber/plastic composites
27. End product testing requirements
28. Explanation of various tests for rubber products
29. Some areas that use recycled rubber

Facts

- *Our research estimates that the manufacturers / processors in the rubber recycling industry dispose 2% to 25% of tires (by volume) that they receive each year to landfills . The industry average is around 13%.*
- *One of the most difficult issues to resolve is the contamination of the final product with fiber. The other pressing issue is metal contamination, which is also a safety hazard.*
- *Lack of uniformity in particle size distribution leads to extensive rework, forcing recyclers to pass the tire aggregate repeatedly through the grinding machines until acceptable quality levels are reached.*
- *Toxicity and lead contamination issues are hard to address at the manufacturer/processor level.*
- *Tires improperly disposed of, either in landfills or left on the surface of the ground, provide excellent breeding grounds for diseases carrying microbes and pests.*
- *Huge tire stockpiles have proven to be a threat to public safety and environmental quality. The occasional fires that arise in such tire stockpiles are costly and difficult to control.*
- *Difference in specific gravity of ground rubber (1.15) compared to asphalt (1.00) leads to settlement of recycled rubber leading to separation from asphalt.*
- *The effectiveness of RAC generally drops in cold weather.*
- *Less than 50% of manufacturers comply with the HIC (Head Impact Criteria).*
- *Most manufacturers do not follow all the recommended standards and specifications and few do not even meet regulatory compliance.*

Storage Quality

Issue: All recycled rubber chips and crumbs may degrade in storage, especially in the presence of iron particles and heat.

Best Practice: This best practice describes precautions that should be taken during the manufacture and storage of whole tires, shredded tires, chips and recycled rubber crumbs. Almost all recycling processes generate heat, sometimes as high as 220-240°F, which in the presence of oxygen, air, can lead to spontaneous combustion. Also, for natural rubber (NR) compounds, presence of iron (Fe) can catalyze the oxidation process, causing rubber degradation. This degradation is accelerated with heat. Presence of any metal can also act as conductor of heat in rubber crumbs. During processing and storage, volatiles and toxicity chemicals may be generated from hot materials. The moisture content of current recycled rubber in specification is at a maximum of 1%. However, the relative humidity and temperature of the material during storage, shipment and disposition prior to use, may cause the moisture content to increase.

Implementation: First, the work force in plant and storage areas should be trained, so that they are aware of the effects of heat and the presence of steel (wire) pieces. During the processing and generation of crumbs, etc., the system and materials need to be cooled either by water or air, so that the temperature is below 200°F to avoid spontaneous combustion. Also, keep recycled rubber free of all metals, especially iron, to avoid conduction of heat and NR degradation. Before the material is stored in bins, piles, etc., make sure that it is cooled and the temperature is well below 200°F. Recycled rubber processors should provide Material Safety Data Sheet (MSDS) available to their employees and to the end-users. Store materials at ambient temperatures and not in tin sheds or tin-roof warehouses. Store recycled materials in a covered and dry area. There have been reports of fires of shredded and ground rubber being stored when not cooled sufficiently after processing. Be aware of proper cooling requirement, i.e., do not store hot ground rubber.

Benefits: Less safety hazard either during recycling processing or storage of recycled rubber. By eliminating/reducing degradation of crumb, it would impart improved compound properties.

Flammability

Issue: Rubber is a good heat insulator and contains a significant amount of volatile organic material. Under proper conditions (heat and oxygen), it may burn.

Best Practice: This best practice describes various steps and precautions for minimizing/eliminating recycled rubber combustion and flammability. All automotive rubber products such as hoses, mats, and belts must use FMVSS 302 standards. Other specifications that rubber material must meet are UL 94, ASTM D470, C542 and C2864. Release of volatiles upon burning of rubber is of concern.

ASTM D4205 describes test methods for determining flammability and combustion properties of rubber materials.

Implementation: Process and store materials at ambient temperatures. Avoid build-up of static electricity which may cause combustion. All processing and storage areas should be strictly "nonsmoking." Recycled rubber handlers need to have information on volatility of the material from MSDS sheets. It is good to avoid static build-up during shredding, grinding and sorting steps. This is best done by properly grounding processing equipment.

Comparitive BTU values

Product	BTU Values
Coke (petroleum)	13, 700 BTU/lb.
Wood (wet - Hog fuel)	4,375 BTU/lb.
Bituminous Coal	12,750 BTU/lb.
Subbituminous coal	10,500 BTU/lb.
Lignite coal	7,300 BTU/lb.
Tire-chip fuel	14,200 BTU/lb.
Tire-derived fuel	15,500 BTU/lb. +
Rubber-derived fuel	16,000 BTU/cu.ft. +
Natural gas	151,000 BTU/gal ++

+ The values differ depending on the amount of wire and fiber in the chip

++ Refers to fuel generated from a combination of non-tire and tire-derived rubber

Benefits: Reduction of fires in manufacturing, storage of recycled rubber and in its use. Also, special care should be taken to remove hot wire during processing to help eliminate fire hazards.

Sampling Procedure

Issue: From a quality point of view, it is important to have consistent and, if possible, uniform procedures for taking samples of crumbs in rubber recycling plants. Those procedures need to be documented and communicated to end-users.

Best Practice: Each rubber recycling plant may have its own sampling procedures. This best practice describes such a sampling procedure used in some of the plants. Two samples, about 125 gms each, of each skid, about 2,500 lbs., are taken by the bagger at the time of bagging recycled rubber. Random samples are also taken by the laboratory personnel for a quality check. Frequency and sampling procedures can be different from these and may be agreed upon between the vendor and customer. High end-use performance product may require more frequent sampling. Customers may use their own sampling procedure to test crumbs received at their plants. For a multi-stage process, samples are taken at the end of each stage. Typically, the recycling industry takes samples of finished crumb just before bagging or shipping into large containers. Field sample size can be as much as one pound, because some tests may have to be repeated.

Implementation: Each manufacturing plant must follow a sampling procedure of its own or the one discussed. Such procedure should be documented and customers be made aware of it. Vendor and customer should agree upon a sampling procedure.

Benefits: Consistent sampling procedures would lead to better quality controls.

Sampling and Testing (QA) plans

Issue: Details of sampling procedures are given in the best practice on "Sampling Procedure". After sampling, testing plans need to be established for quality controls.

Best Practice: After sampling, tests described in ASTM D5603 are run. These tests are: % extractables, ash content, NR and rubber hydrocarbon contents, % heat loss (moisture) and carbon black content. Two samples per truck load (5 skids) are run for percent moisture content and bulk density on randomly selected samples, either sampled by a bagger or QC person. Percent ash, carbon black, rubber hydrocarbon, and acetone extract are run once per day per shipment of each truck load. These are done according to ASTM D297. For ambient ground materials, moisture content and bulk density, measurements are made on every skid because of possible moisture content variations in feedstock.

Particle size and particle size distribution measurements are made by using the Ro-Tap method (ASTM D5644). Weight percents are plotted as a function of particle size to get the particle size distribution. For higher performance products (e.g., tire carcass compound), variations in particle sizes and distributions are noted. Materials meeting customers' specifications are shipped along with the analysis data for each skid. For lower level performance products (e.g., mats), specification tolerances are much wider and the report may be submitted as agreed upon between vendor and customer.

Implementation: Recycled rubber processors should develop a quality control plan (if not already in existence) charting actual results and any specification limits. This should especially be done for moisture content, bulk density and particle size distribution.

Benefits: Better quality control.

Cryogenic Processing (1 of 2)

Issue: Cryogenic processing employs liquid nitrogen to lower rubber material temperature to well below its freezing point. While frozen, the rubber is shattered with a mill or similar piece of equipment. The resulting material has clean, fractured surfaces and low steel and fiber content because of the clean breaks between the fiber, steel, and rubber.

Best Practice: The temperature of liquid nitrogen is -320°F at atmospheric pressure. Most rubber compounds freeze at their glass transition temperature of about -80°F. At temperatures below the glass transition temperature, the rubber changes from an elastic material to one that is brittle and easy to grind by impacting it. The use of cryogenic temperatures can be applied at any stage of size reduction of scrap tires. The choice of feed material for a cryogenic stage depends on the feed material available and the characteristics of the desired products. Typically, the size of the feed material is a nominal 2-inch chip or smaller.

The chips are fed at a constant rate into a heat exchanger where they are cooled by direct contact with liquid nitrogen. The most efficient pre-cooler utilizes counter-current heat exchange, where the liquid nitrogen is sprayed onto the rubber near the exit end of the pre-cooler. The liquid nitrogen is vaporized as it cools the rubber and the cold nitrogen vapor is passed back toward the feed end, where it is further warmed by the rubber. The warm nitrogen gas is vented to a safe location while the cold rubber is fed to the grinding mill.

The temperature of the frozen rubber exiting the pre-cooler is controlled to a temperature ranging from -150°F to -320°F. The choice of temperature depends on the intensity of grinding to be done in the following stage. Typical refrigeration efficiencies for rubber cooled to -150°F is 0.5 pounds of liquid nitrogen for each pound of rubber. Fully pre-cooling to -320°F increases the nitrogen consumption to about 0.75 pounds per pound of rubber. The product particle size is somewhat finer with colder temperatures.

The cold rubber is ground in a hammer mill producing rubber product ranging from 4 mesh down to very fine powder. For scrap tires, the steel is separated out of the product by the use of magnets and conveyed to a collection hopper. It contains very little entrapped rubber and fiber making it suitable for sale as a byproduct. The fiber is fluffed in the hammer mill and removed by aspiration and screening. The rubber crumb is then heated in a dryer and separated into the desired size ranges by screening. Because of moisture pickup in the cryogenic process, it should be noted that drying is required.

Cryogenic Processing (2 of 2)

Issue: Cryogenic processing employs liquid nitrogen to lower rubber material temperature to well below its freezing point. While frozen, the rubber is shattered with a mill or similar piece of equipment. The resulting material has clean fractured surfaces and low steel and fiber content because of the clean breaks between the fiber, steel, and rubber.

Additional very fine crumb is generally 30 mesh or smaller. If desired, a secondary high-intensity grinding stage is used. The feed material for this stage is usually clean, 4 mesh rubber crumb. The process is the same for clean industrial or post consumer scrap, except there are no steel and fiber removal steps and only one cryogenic grinding stage is needed. Liquid nitrogen requirements for this stage are 0.75 pounds of nitrogen per pound of rubber and up, depending on the crumb size needed. New mills are being developed to economically produce 80 mesh and finer materials.

Besides the process described, there are processes that employ ambient and wet grinding technology after the first cryogenic grinding, to further reduce the size of recycled rubber.

Implementation: The first step to implement cryogenic processing is to identify which material to process and to understand the application or market needs for its crumb characteristics. Because this process is sensitive to operating costs, it is best to engage a company that has the experience and expertise to design a turnkey system. A turnkey system optimizes the equipment and operating costs to produce an acceptable product from the available feed material.

Benefits: The benefits of cryogenic grinding include low power requirements, reduced power requirements, finer product, reduced maintenance, cleaner product and product morphology. The disadvantages include the cost of liquid nitrogen and product morphology.

Ambient Versus Cryogenic Grinding (1 of 2)

Issue: There are several processes that can be used to produce ground rubber crumb. Two of the most common are ambient grinding, using various types of grinding mills and cryogenically grinding of rubber by chilling with liquid nitrogen. This section will review the attributes and properties of crumb rubber produced by both methods.

Best Practice: Vulcanized scrap rubber is first reduced to a 2" x 2" or 1" x 1" chip. This can be further reduced using ambient ground mills or frozen and "smashed", or ground into fine particles while frozen, using cryogenic grinding. This best practice will compare the two methods.

The ambient process often uses a conventional high powered rubber mill set at a close nip, and the vulcanized rubber is seared and ground into a small particle. It is common to produce 10 to 30 mesh material using this relatively inexpensive method to produce relatively large crumb. Typical yields are 2000-2200 pounds per hour for 10-20 mesh and 1200 pounds per hour for 30-40 mesh. The finer the desired particle, the longer the rubber is let run in the mill. In addition, multiple grinds can be used to reduce the particle size. The lower practical limit for the process is the production of 40 mesh material. Any fiber and extraneous material must be removed using an air separation or an air table. Metal is used using a magnetic separator. The resulting material is fairly clean.

The process produces a material with an irregular jagged particle shape. In addition, the process generates a significant amount of heat in the rubber during processing. Excess heat can degrade the rubber and if not cooled properly combustion can occur upon storage.

Cryogenic grinding usually starts with chips or a fine crumb. This is cooled using a chiller. The rubber while frozen, is put through a mill. This is often a paddle type mill. The Best Practice on Cryogenic Grinding covers this process in detail. The final product is a range of particle sizes which are sorted and either used as is or passed on and further size reduction performed e.g. using a wet grind method. A typical process generates 4000 to 6000 pounds per hour.

The cryogenic process produces fairly smooth fracture surfaces and little or no heat is generated in the process. This results in less degradation of the rubber. In addition, the most significant feature of the process is that almost all fiber or steel is liberated from the rubber, resulting in a high yield of usable product and little loss of rubber. The price of liquid nitrogen has come down significantly recently and cryogenically ground rubber can compete on a large scale with ambient ground products.

Ambient Versus Cryogenic Grinding (2 of 2)

Issue: There are several processes that can be used to produce ground rubber crumb. Two of the most common are ambient grinding using various types of grinding mills and cryogenically grinding of rubber by chilling with liquid nitrogen. This section will review the attributes and properties of crumb rubber produced by both methods.

The following chart compares the properties and benefits of ambient and cryogenically ground rubbers.

Physical properties	Ambient ground	Cryogenic Ground
Specific gravity	Same	Same
Partical shape	Irregular	Regular
Fiber content	0.50%	nil
Steel content	0.10%	nil
Cost	Comparable	Comparable

The following chart shows the particle size distribution for two typical 60 mesh ground rubbers. One was prepared ambiently and the other cryogenically.

Amount retained	Ambient	Cryogenic
30 mesh	2%	2%
40 mesh	15%	10-12%
60 mesh	60-75%	35-40%
80 mesh	15%	35-40%
100 mesh	5%	20%
pan	5-10%	2-10%

Benefits: As mentioned above

Crumb Sizing

Issue: The production processes used to make ground or crumb rubber usually produce a range of particle sizes. It is necessary to sort and classify the ground rubber for use. This is accomplished using various screening techniques.

Best Practice: There are many types of equipment for sorting and classifying ground rubber. They are all based on some type of rotating, vibrating or shaking screen. The type found to be the most useful for dry screening uses an up and down shaking motion in conjunction with a scrubbing motion. In addition, there are vibrating screens, rotor sifter screens and variations of all these techniques. The rotor sifter screen is particularly effective for wet screening.

The output for the screen is based on the particle size of the rubbers being screened and the surface area of the screen. The larger the surface area of the screen the higher the yield, and the larger the particle size the higher the output. Screens are most effective when sorting 10 to 40 mesh ground rubber. A typical yield is 1000 pounds per hour. At the smaller mesh sizes, the yield falls off dramatically. On the very fine particles, smaller than 100 mesh screens are ineffective.

Implementation: To get equipped to do screening one must purchase a screen or contract the service.

Benefits: The major benefit of crumb sizing and screening is the classification of the ground rubber into useful sizes. Some applications require small mesh sizes and some can use larger sizes. The screen allows the optimum product for each application.

Bulk Density

Issue: Control of particle size and density is important from storage, shipping and purchasing points of view. As particle size decreases, bulk density increases. ASTM D5603-94 cites method 0297 section 16 for determining specific gravity. This method works well for single piece & chunks of rubber, but does not work well for crumbs with higher surface area.

Best Practice: This best practice advocates use of bulk density rather than specific gravity for recycled rubber particulates. There is no such ASTM specification for crumbs. However, ASTM 1513 which is for carbon black pour density can be used for this purpose. The method calls for filling a cylindrical container, 624-cm^3 capacity, with carbon black up to the rim and weighing it. Knowing the mass and volume, bulk density can be calculated. Here, moisture content is very important; high moisture content may give erroneous bulk density values. Bulk density should be expressed as Kg/m^3 or $lbs./ft.^3$. Expected bulk density of current recycled rubber product is in the range of 28-34 $lbs./ft.^3$.

Implementation: Bulk density should be included in the material specification sheet of recycled rubber crumbs. Actual specification for a material should be determined at the vendor's plant site and agreed upon between vendor and the customer. Vendor should describe the technique used for determining the bulk density. Also, information on moisture content should be provided by the vendor.

Benefits: Good quality control, uniform, and standard material availability in the market.

Devuclanization – Chemical

Issue: The thermodynamically irreversible reaction of sulfur and rubber molecules creates a three dimensional network of sulfur polymer molecules. These crosslinks create the useful viscoelastic properties of rubber compounds. After the rubber particle has used up its useful life, it is difficult to devulcanize the rubber compound and produce a useful material.

Best Practice: A new system for reclaiming scrap tire rubber is being marketed by STI of America. This system incorporates a dry powdered or masterbatch mixture of reportedly common chemicals that are mixed into crumb rubber.

The STI process involves taking a small particle size rubber, typically 30 mesh, produced by cryogenic grinding. A mixture of the dry chemicals, know as DeLink, is added to the rubber in a Banbury or on a mill. The rubber, after several minutes of smoking, becomes a dry, crumbly material. With additional time on the Banbury or in the mill, the rubber eventually becomes a formable mass of "devulcanized" rubber. The manufacturer reports that the resulting "devulcanized" material can be used for incorporation into virgin rubber products such as tires, mats, footwear, etc..

Benefits: The major advantage to the DeLink process is that it is done by the customer in their own plant and it works on many polymers. The disadvantages are cost and the fact that it works best with polysulfidic compounds. DeLink works best when the “devulcanized’ rubber is incorporated back into a virgin compound of the same composition as the original scrap.

Devuclanization – Microwave

Issue: The thermodynamically irreversible reaction of sulfur and rubber molecules creates a three dimensional network of sulfur polymer molecules. These crosslinks create the useful viscoelastic properties of rubber compounds. After the rubber article has used up its useful life, it is difficult to devulcanize the rubber compound and produce a useful material.

Best Practice: Microwave energy is part of the electromagnetic spectra. The process utilizes frequencies of 915 and 2450 MHz. according to the Goodyear Tire microwave patent. The process produces rubber material that is reportedly devulcanized using impulses that can rupture atomic and molecular bonds. Microwave devulcanization involves exposing rubber materials to microwave energy under controlled conditions. These conditions theoretically sever sulfur bonds and produce a rubber material that can be compounded and used in virgin rubber compounds.

Implementation: Goodyear Tire and Rubber Co. obtained a patent for the use of microwave energy in “devulcanizing” rubber compounds in the late 1970’s. They used the process to “devulcanize” short ends of hose trim and out of specification EPDM hose. The resulting material, with the proper compound adjustments, such as oil/filler ratios, could be added back into non-OE and other industrial EPDM hose and industrial goods. The process was used for many years and then abandoned due to unfavorable economics.

Benefits: The major benefit of the process was to take scrap rubber ends and out of tolerance EPDM hose and produce a useful recycled product that was added to new rubber goods.

Devuclanization – Ultrasound

Issue: Vulcanization introduces sulfur crosslinks between the elastomer chains. This introduction causes an irreversible reaction. The crosslinks are thermally stable and difficult to rupture. When a rubber product has had its useful life completed it would be desirable to “devulcanize” or remove the crosslinks.

Best Practice: This process uses ultrasonic frequencies that run from 20,000 hertz up to 10 MHz . The lower frequency end is the upper limit to human hearing. The 10 MHz is used to inspect metals and the 0.5 to 2.5 MHz has been used to inspect rubber. Ultrasonic devulcanization reportedly uses frequencies from 20,000 to 50,000 hertz.

Ground scrap rubber of 10 to 30 mesh is extruded and exposed to ultrasonic energy. The ultrasonic energy is believed to create molecular cavitation of the chains. The result is cleaving of the sulfur bonds preferentially over the polymer chains. The sulfur bonds are known to be less stable than the carbon-to-carbon bonds and thereby break first.

Implementation: A crumb “devulcanized” rubber is obtained from the end process. This crumb can be used as is and with sulfur and accelerators added, vulcanized into a rubber product or blended into other virgin rubber compounds.

Benefits: The ability to incorporate rubber that has been “devulcanized“ rather than reclaimed into a virgin compound should improve the compatibility and homogeneity of the compound, resulting in improved mixing, processing and properties. The dynamic properties of the compound should especially be improved. If the rubber is truly “devulcanized”, higher levels of recycled material should be able to be used. This process should generate recycled rubber that is compatible in a wide range of compounds and can be used in both molded and extruded goods.

Additives for Surface Modification

Issue: Virgin rubbers are high viscosity liquids. Recycled rubbers are produced from used rubber items that are higher in viscosity and molecular weight. As a result, it is usually difficult to get good bonding and dispersion of recycled rubber in virgin rubber. Surface modifiers are added to improve the compatibility of recycled rubber with virgin rubber.

Best Practice: A tremendous amount of research has been done in this area. The most practical applications of the surface modifiers are shown below:

Material	Use
Urethanes	Moisture Seal
SBR Latex	Binder/Wetting Agent
NR Latex	Binder/Wetting Agent
Ricon 100 (Sol SBR)	Binder/Adhesive
Vestamer	Thermoplastic Binder
Vestol 28	Curable regrind wetting agent
Strukol 40 MS	Curable regrind wetting agent
Flow PO	Binding Agent

Implementation: The materials listed can be added to virgin compounds at application dependent levels during the mixing stage. The ultimate application of the compound will determine the type and amount of additive that needs to be used. Any manufacturer making rubber compounds is a candidate to use these materials.

Benefits: The reason for using surface modifiers is to improve compatibility, properties, and mix consistency when using recycled rubber. The urethanes make up 90-95% of surface modifiers used for modifying recycled rubber.

Extrusion

Issue: One of the common methods used to form rubber products is extrusion. This Best Practice reviews the common factors for equipment and products made from the extrusion method.

Best Practice: Unvulcanized rubber is really a very high viscosity liquid. The unvulcanized rubber can be shaped and formed using a die.

There are many different types of extruders. The major types are hot feed, cold feed and mixing extruders. A hot feed extruder requires the rubber compound be preheated prior to being introduced into the extruder. A cold feed extruder has a more aggressive screw design and *accepts cold rubber compounds. A mixing* extruder has different screw pitches and usually has pins inserted in the shaft to introduce violent flow and mixing action.

Extruders are commonly used in tire manufacture to pre-form treads, sidewalls, bead apex compounds and various wedges and filler components. Hot feed extruders were commonly used for this purpose but are being replaced by the smaller more efficient, but more costly cold feed extruders. As the name implies, mixing extruders are used to mix rubber compounds. These extruders find limited use in rubber, but are commonly used in the plastic industry.

Of particular note to recycled rubber interests is that when ground rubbers are added to virgin rubber compounds the die swell or expansion of the final product is increased. The smaller the particle size the lower the die swell. The higher the concentration the higher the die swell. In addition, extruders can impart a smooth surface to the final product. Recycled ground rubbers often create a rough appearing surface. This surface type is often objectionable, such as with automotive weather-stripping. This condition has limited the acceptance of recycled rubber in such products.

Implementation: Extruders are used throughout the rubber industry to produce a wide range of final products.

Benefits: The major benefit of an extruder is the ability to easily form and shape rubber compounds for preparation for other steps in manufacturing, or to actually form final products with a relatively simple piece of equipment that is easily maintained and lasts a long time.

Hot Molding (1 of 2)

Issue: Over 70 percent of all rubber products are produced by hot molding. Hot molding refers to compression, transfer, and injection molding. Recycled rubber is commonly used in all of these processes.

Best Practice: There are three commonly used methods for hot molding. These are compression, transfer, and injection molding. All three involve placing an unvulcanized rubber compound into a mold and exerting pressure and applying heat. They differ on how the rubber is introduced into the mold, mold pressure, and curing time and temperature. Compression molding is the most common and is used to make pneumatic tires, solid tires, mats, and many small-to-medium-sized mechanical goods for automotive and industrial markets. When the number of parts to be made becomes large, then one often considers injection molding. Molded goods in many cases can use ground recycled rubber and reclaimed and other forms of recycled rubbers.

Compression molding involves placing a performed slug of rubber into a preheated mold. The rubber weighs slightly more than the final part. The mold is held in a compression press. The press is closed and the part held under temperature and pressure from 10 to 40 minutes depending on the temperature and pressure. Typical pressures are 2,000-3,000 psi at 280-350°F. Compression molding can use 1040 mesh ground recycled rubbers in parts experiencing low dynamic stress.

The tensile strength of the rubber is lowered and the viscosity of the rubber is increased when they are incorporated. However, there is usually sufficient force for the rubber to flow even with the higher viscosity. Some of the new surface modified recycled rubbers do process better than their untreated counterparts. In ultra-high performance compression molding, 60-120 mesh is employed.

Transfer molding also uses a press with parallel platens. However, the rubber is introduced as a slab into the upper transfer pot. It is cold or has been warmed slightly. The transfer piston is pushed against the rubber slab and this forces the rubber through openings in the top of the mold and into the cavities. The mold is then held under temperature and pressure. The times and temperatures are similar to those used in compression molding. Transfer molding requires the rubber to flow through an orifice in the upper mold plate. This means the viscosity control of the rubber is critical. It is usually necessary to use ground recycled rubber in the 40-80 mesh size to get sufficient flow and minimal effect on physical properties for transfer molding.

Hot Molding (2 of 2)

Issue: Over 70 percent of all rubber products are produced by hot molding. Hot molding refers to compression, transfer, and injection molding. Recycled rubber is commonly used in all of these processes.

Injection molding uses an injection molding press. The rubber is fed as a strip into the machine, warmed and heated with a screw and injected hot into the mold cavities through a series of runners and sprues. Curing is done at high temperature and pressure and is usually quick (e.g., from 30 to 120 seconds) at 350°F. The flow rates are high and the gates and sprues may be very small. As a result, in many cases ground recycled rubbers might inhibit the efficiency of the process. Also many high dynamic stress parts like bushings, gaskets, and seals are made by injection molding. These parts allow minimal use of ground recycled rubber. The amount used is also small. Finally, 60-120 mesh ground recycled rubber at low concentrations (from 2 to 5 percent) is generally used in injection molding.

Implementation: Any of these processes are implemented by buying the appropriate press and mold. The ground recycled rubber is introduced in the mixing stage.

Benefits: First, compression presses and molds are the least expensive of the three and the least efficient. However, for small volume runs they are usually used. Secondly, the transfer mold process can often be done in compression presses. This process allows more parts to be made at one time. It also wastes a lot of rubber with the transfer pad. Thirdly, injection molding is usually used for high volume part runs. The presses and molds are the most expensive of the three processes. However, it is also the most efficient since the rubber is injected hot and cured at high temperature. Injection molding also generates a lot of scrap. Ground recycled rubbers are added to reduce cost and improve the removal of trapped air during vulcanization.

Cold Molding

Issue: In Germany, during W.W .II, the Germans invented a process for recapping truck tires using the ambient desert heat (160-220°F). This became known as cold molding or cold capping. This process has successfully incorporated scrap rubber into its process.

Best Practice: Most rubber products are cured at temperatures of 280 - 400°F. The cure times vary from seconds to minutes. For passenger tires, typical curing conditions will be 350-400°F, while truck tires are cured at 285-320°F. In cold molding, the tread is cured in a compression mold using a platen press. The compound is typically an SBR-PBD blend reinforced with carbon black and extended with aromatic oil. This will be cured in 20-30 minutes at 320-340°F. A squeegee or adhesion layer of uncured natural rubber is mixed and calendered separately. The rubber is designed to cure at a much lower temperature such as 210-230°F.

The tire to be retreaded has the old tread stripped from it. The surface is kept clean and a layer of cement adhesive is applied to the tire. The bonding layer, typically 0.040-0.060" thick is applied to the tire. The pre-cured tread is applied to the tire and stitched to the tire with pressure. This is all done at ambient temperature. The tire has a metal band wrapped around the outside of the tread and the entire assembly is placed in a rubber envelope that is heat resistant. A bladder is placed inside the tire and steam is applied to the inside and heat to the outside of the tire. The temperature is maintained at 210-230°F for 45-75 minutes depending on the tire thickness. The tire is removed from the envelope, bladder and metal band removed after curing and the result is a retreaded tire.

Implementation: Electrical and steam resources are required. The process is relatively inexpensive compared to hot molding. With regard to recycled rubber, it is common practice in a cold molding manufacturing process to grind scrap of constant composition and mix it into virgin treads.

Benefits: The major advantage of the cold molding is less degradation to the tire cords and compounds due to heat and oxidation. In addition the bands and envelopes are generally less expensive than hot molding equipment.

Moisture Retention/Absorption

Issue: Moisture is present during the entire process of grinding and processing recycled rubber. This Best Practice describes the accepted levels of moisture in the process.

Best Practice: Water (moisture) is present during the entire grinding and processing of recycled rubber. This moisture is inherent in the polymer itself from an outside source associated with the polymer. The accepted level of moisture in rubber materials is 1% CAP (Current Accepted Practice). The level of moisture typically runs at 1% or less in most rubber materials.

Moisture can cause many problems in rubber materials including:

1. Material Handling - Too much moisture in a compound can cause caking and inhibit flow during processing. Calcium carbonate or other anti-caking agents can be used to help this problem.
2. Acidity - Moisture build-up in an elastomer can lead to acidic conditions within the polymer which causes cure retardation, especially when clay fillers are involved in the compound.
3. Polarity - A high moisture content (2-3%) leads to increased polarity in the compound and can lead to poor bonding properties. This is especially harmful when working on retreading tires. Moisture is especially problematic in the processing stage. Materials that are extruded or calendered are the most sensitive due to the lower processing pressure created by the moisture.

Implementation: To minimize the moisture level in reclaimed rubber, store the material in a cool, dry place. When using dry materials, use a dessicant to control the moisture level in the compound, especially those intended for extrusion.

To test materials for moisture content, ASTM D 297 is the test method of choice. This method utilizes a 105°C weigh-dry technique.

Benefits: Water is beneficial in the cooling of rubber during processing. However, excess water can affect the cure rate if it is at a high level. In regards to recycled rubber, it is important to keep the ground or crumb material dry so as to maximize the material's ability to be mixed into a virgin compound as an additive. Excess moisture will devalue a recycled rubber material and hinder its ability to be used effectively in many applications.

Contaminates – Incompatible Rubber Polymers

Issue: In producing recycled rubber, contamination is a possibility. This includes objects that are foreign as well as materials that are included in the product being recycled. In many instances, various types or grades of rubber may be incompatible when blended together. Incompatibility can lead to poor processing and performance characteristics.

Best Practice: In the recycling of tires, the obvious concern is over dirt, mud, and foreign matter that might be contained on or in the tire. Stones are an area of primary concern since they can do damage to processing equipment as well as contaminate the final product. Therefore, it is necessary to use general sanitary conditions that eliminate extraneous matter from the process. Within some OE and specialty tires there is a layer of tire sealant for puncture resistance. This layer (Gen-Seal, Royseal. etc.) is usually soft and composed of low molecular weight polymer, resin and filler, and is partially cured. This layer should be avoided if possible because they can cause downstream problems when working with small particle size materials. Other contaminants of concern in tire, hose, and belt recycling and grinding are the textile and steel reinforcing members. These are removed in the case of the metal with a powerful magnetic separator. The fiber is removed using air cyclone separation during processing. Small amounts of fiber are often found in large particle size whole ground tire. On the other hand, cryogenic grinding is especially effective at removing fiber and steel from the recycled rubber. One item that the recycler of rubber has to be aware of is to avoid incorporating specialty elastomers containing peroxides and halogens into general purpose polymers. Many hoses, belts, roofing materials, and O-rings contain specialty elastomers that will be less than compatible. These materials should only be co-mingled with themselves. The small amount of halogen in the inner liner of tubeless tires is not a problem and it is easily ground and incorporated into whole ground tire recyclate. EPDM, butyl, and nitrile rubber should also be avoided for blending into ground tire recyclates.

Implementation: The best way to avoid metal contamination is to use a magnetic separator in the process line. Fiber is best removed by air separation, and dirt and mud are best removed by thorough washing.

Benefits: The major benefit of keeping the recycled system clean is obvious - the recyclate has more useful properties and is more reproducable from lot to lot.

Contaminates – Fiber and Steel (1 of 3)

Issue: Tire recycling processes designed to reduce rubber to small particle sizes result in the liberation of steel and fiber components of the tire. Generally, both the steel and the fiber need to be removed. Scrap tires contain approximately 70% rubber, 15% steel, and 15% fiber by weight. These percentages vary depending on the type of scrap tire.

Best Practice: In general, the best practice for the removal of both fiber and rubber is to remove the material as early in the process as possible. Steel tends to have an adverse effect on equipment longevity and the fiber tends to limit throughput of rubber through the process. Fiber, as it passes further through the system becomes shortened to the extent that it becomes more difficult to remove from the rubber using commercially available equipment.

Steel Removal -- It is best to remove truck tire beads before any size reduction is done. Truck tire beads are extremely difficult to shred and cause significant equipment wear. Some operations choose to shred truck tires without removing the bead. Passenger tire bead wire is much easier to process and the cost/benefit analysis is required to determine if the benefits of removing the bead prior to size reduction outweigh the costs. There is an external scrap metal market for clean bead wire. Bead wire can be cleanly removed by using commercially available bead pullers. These devices cleanly rip the bead wire from the tire.

Size reduction of the tire to 1” particle size liberates 50-70% of the steel in the tire. This steel can be removed with overband magnetic conveyors or drum magnetic configurations that are commercially available. The degree of steel removal at this stage is determined by the desired degree of rubber contamination in the steel. Rubber contamination reduces the value of the steel in the scrap metal market. The degree of steel removal is adjusted by varying the strength of the magnetic field used to pull the steel from the material stream. The magnets can be purchased with different magnetic field strengths or the magnets can be moved further from the material. All conveyors and guards around the magnetics must be fabricated from non-magnetic material to avoid build-up of steel on this equipment.

This principal steel separation should be performed after most size reduction stages. As the rubber/steel/fiber mixture is further size reduced, the fiber also becomes liberated. There is a potential for contamination of the steel with the fiber, if the majority of the fiber is not removed prior to this stage. It is particularly important to use drum magnet steel separation on the final rubber product before packaging. Most ground rubber customers have stringent guidelines limiting steel content in the product they purchase.

Contaminates – Fiber and Steel (2 of 3)

Issue: Tire recycling processes designed to reduce rubber to small particle sizes result in the liberation of steel and fiber components of the tire. Generally, both the steel and the fiber need to be removed. Scrap tires contain approximately 70% rubber, 15% steel, and 15% fiber by weight. These percentages vary depending on the type of scrap tire.

Fiber Removal - Various techniques exist for fiber removal. The most effective method depends on the size reduction achieved on the tire material.

Tire material that has been reduced to a nominal size of 3/8" has a large amount of fiber liberated. The fiber at this stage is approximately 1/2" to 3/4" long. At this stage the fiber can be separated using mechanical vibrating screen tables and pneumatic systems.

In a single pass system, the tire material, a mixture of rubber and fiber which has the majority of steel removal, is passed over an optimally laded vibrating screen table. The screen size is adjusted to maximize the fiber content in the oversize discharge. Note there will be a large concentration of large rubber pieces in the fiber. The undersize, which still contains fiber, continues on to the next stage of size reduction. The remaining fiber is removed at a later stage.

In a recirculating system, the tire material is also passed over a vibrating screen table. The screen size is adjusted to minimize the amount of fiber passing through the screen, yet maintain a steady flow of material for further size reduction. The oversize is discharged and passed through a two roll mill. The mill reduces the size of the rubber and shears it off of the fiber while maintaining fiber length. This material is then recirculated onto the screen table. The vibrating nature of the screen tends to stratify the material on the screen, so that the fiber is on the top of the oversize and the rubber is on the bottom. The fiber can be removed pneumatically by "vacuuming" the long fiber off the top of the screen. It can also be separated using mass differential after it has been discharged from the screen oversize outlet.

The fiber in the tire material that passes on for further size reduction tends to fray or be reduced to very small particle sizes. This fiber can be removed using commercially available density separator tables. The density separator table is a vibrating, air fluidized bed which is angled upward from inlet to discharge. The bed is enclosed by a hood with a low pressure outlet at the top to draw off air from the bed and small fiber particles from the tire material. The material is dropped onto the bed and vibrates up the table. The more dense and massive the particle, the further up the table it travels. The remaining fiber in the material is collected in combination with the smallest particles at the least dense material discharge.

Contaminates – Fiber and Steel (3 of 3)

Issue: Tire recycling processes designed to reduce rubber to small particle sizes result in the liberation of steel and fiber components of the tire, Generally, both the steel and the fiber need to be removed. Scrap tires contain approximately 70% rubber, 15% steel, and 15% fiber by weight. These percentages vary depending on the type of scrap tire.

Implementation: Tire recyclers must consider the markets for the materials they will be generating. These markets will dictate the type of processes required to meet the market demands. An analysis of commercially available equipment capable of meeting processing needs is required. A design layout is also required before matching capacity and equipment size requirements.

Benefits: The benefits of following this best practice are cleaner, higher value materials that are very attractive to potential customers.

Fillers – Recycled Crumb Rubber (1 of 3)

Issue: Ground rubber from tires, buffings, and other sources is commonly added into rubber compounds in order to lower costs and to use recyclate.

Best Practice: The size of the ground rubber material varies from 6 to 100 mesh. Smaller particles are available but are not commonly used. When ground rubber is added as a filler, three things almost always occur:

1. The viscosity of the rubber compound increases
2. The tensile strength is lowered
3. The dynamic properties are reduced

One of the biggest reasons manufacturers use ground rubber as fillers in virgin compounds is to reduce costs. The ground rubber costs less than the virgin compound and the price reduction is generally in proportion to the level of ground rubber added. A lot of development work is taking place in this area with regards to surface modification, devulcanization, and treatments and binders to minimize the negative effects on properties, and in fact enhance the properties of compounds containing ground rubber.

Implementation: Ground rubber is added into the rubber compound using an internal mixer. It is commonly used at levels from 5 to 75 percent, depending on the application. Tires and high performance compounds use from 3 to 10 percent, and mats, dock fenders, bedliners, and similar low dynamic stress products can use from 10 to 75 percent ground rubber. The smaller the particle size of the rubber, the less the negative effect on the compound properties.

Benefits: The following data shows the effects of a 20 mesh, ambient-ground rubber compounded into an SBR1502 compound. The ground rubber has been evaluated at 17-, 33-, and 50-percent levels. The compound recipe is as follows:

Fillers – Recycled Crumb Rubber (2 of 3)

Issue: Ground rubber from tires, buffings, and other sources is commonly added into rubber compounds in order to lower costs and to use recyclate.

Ingredient	Level, phr
SBR 1502	100.0
Zinc Oxide	5.0
Steric Acid	1.0
TMQ	2.0
N660 Carbon Black	90.0
Aromatic Oil	50.0
Sulfur	2.0
MBTS	1.0
TMTD	0.5

The 20 mesh crumb was added at 17, 33 and 50%

The properties of the materials are as follows:

	0% Ground	17% Ground	33% Ground	50% Ground
Mooney Viscosity	40.0	61.0	91.0	111.0
Rheometer Max Torque	59.0	47.0	33.0	34.0
tc 90, min.	2.5	2.4	1.8	2.0
Tensile Strength	1470.0	1150.0	870.0	560.0
Ultimate Elontation %	330.0	330.0	300.0	270.0

Fillers – Recycled Crumb Rubber (3 of 3)

Issue: Ground rubber from tires, buffings, and other sources is commonly added into rubber compounds in order to lower costs and to use recyclate.

The following data shows the effect of concentration and particle size of a cryogenically ground rubber on an EPDM compound.

CryOfine Ground Rubber used at 10% levels (except control at 0%)

	Control	40 Mesh	60 Mesh	80 Mesh	100 Mesh
Tensile Strength, psi	1410	1290	1430	1470	1440
Ultimate Elongation, %	410	330	340	400	380
100% Modulus, psi	535	490	530	490	480
300% Modulus, psi	1180	1220	1230	1230	1220
Hardness, Shore A	73	70	70	70	71
Die C Tear, ppi	193	175	173	171	172

CryOfine Ground Rubber used at 20% levels (except control at 0%)

	Control	40 Mesh	60 Mesh	80 Mesh	100 Mesh
Tensile Strength, psi	1410	1230	1360	1460	1410
Ultimate Elongation, %	410	320	390	390	390
100% Modulus, psi	535	450	500	460	460
300% Modulus, psi	1180	1220	1300	1200	1160
Hardness, Shore A	73	72	70	69	68
Die C Tear, ppi	193	178	163	165	181

Recycled Rubber Content Effects on Properties of Virgin Compounds

Issue: Recycled rubber content in a rubber compound may depend on two factors. One, required by the customer. The other is the limit in use of recycled rubber without any significant adverse effect on compound properties.

Best Practice: Customers may require the use of certain amount of recycled rubber in rubber products. For example, Ford has indicated the use of 25% recycled rubber in automotive rubber parts, except in tires where it might be up to 10%. In general, for high performance products (e.g., tire, belts) use of recycled rubber would be lower than for lower level performance products. The actual amount will depend on desired properties of the compound. However, some guidelines given here can be used for different processes, along with compound property requirements. For compression molding, particles as large as 6-8 mesh can be successfully used, e.g., in railroad crossing pads. In mechanical and compression molded goods such as mats, semi-pneumatic tires, bumpers, shocks, 10-30 mesh are commonly used at up to 30 - 40% levels.

For injection molding, 40-80 mesh recyclates are required to get good flow through the gates and sprues and to produce an acceptable surface finish. Levels up to 10% are commonly used.

For extrusion and calendered goods, 80-120 mesh recyclates are used. This is because the surface finish in these products requires the final product to be smooth. The larger particles do not give the desired smoothness. Three to ten percent levels of recyclates are used with 5% being typical.

Implementation: A customer may require a vendor to use a certain percentage of recycled rubber for environmental reasons and to be a good corporate citizen. The actual amount may depend on specification of product properties. Normally use of 5 to 10% recycled rubber with 60-100 mesh size particles does not significantly affect rubber properties.

Benefits: Use of recycled rubber will minimize environmental issues such as storage of old tires and fire hazards. Its use may lower the cost of rubber products.

Fillers for Rubber Components – Carbon Black

Issue: Almost all virgin rubber compounds (99%) utilize either carbon black and inorganic fillers, such as precipitated or fumed silica, clay, ground or precipitated calcium carbonate, titanium dioxide, zinc oxide and several others. These materials are used as reinforcing agents and extender fillers for rubber compounds.

Best Practice: This best practice reviews the black fillers used to reinforce rubber compounds such as those used for tires, hoses, belts, mechanical goods, and other practical rubber goods. The major filler used in tire compounds is carbon black. Carbon black is made by the controlled cracking of low grade hydrocarbons into fine particle carbon particles. These are known as furnace blacks. Two other processes, thermal black and channel black are also used as small volume carbon black for specialty uses. Over 97% of all carbon black is produced by the furnace process.

Recycled rubber contains carbon black in the same proportions as the virgin rubber from which it is recovered. High reinforcing black in the virgin rubber will possess more reinforcing properties in the recycled form. However, the properties of recycled rubber are more directly related to particle size. The smaller the size, the more reinforcing the material.

Implementation: Carbon black is mixed into compounds at controlled levels using a Banbury mixer. The type of carbon black used depends on the intended application of the compound.

Benefits: The higher the DPB Absorption, the higher the structure of a carbon black. As structure increases, the abrasion resistance increases and the dynamic properties decrease. As particle size decreases, reinforcing properties increase.

Fillers for Rubber Components – Non Black (1 of 2)

Issue: Almost all virgin rubber compounds (99%) utilize either carbon black or inorganic fillers such as precipitated or fumed silica, clay, ground or precipitated calcium carbonate, titanium dioxide, zinc oxide and several others as either or both reinforcing agents or extenders for rubber compounds. Recycled rubber contains the same fillers as the virgin rubber from which the recyclate was produced.

Best Practice: There are significant quantities of mineral fillers used in rubber compounds. These compounds include both natural and synthetic fillers. The major synthetic filler used is precipitated silica. This silica is 0.02 micron in average particle size. The silica is added to enhance the modulus and tear strength of tire compounds. It is also used as an ingredient in fabric and wire bonding systems. The silica, along with resorcinol and hexamethylene melamine, is used extensively in wire adhesion systems. Typically, from 10 to 12 phr of silica is used. In addition, several tire compounds designed for very low rolling resistance have 60 phr of silica coupled with a silane coupling agent to achieve very low tangent delta values in the tread. The silica has an average surface area from 150 to 175 square meters per gram. About 200 million pounds of silica are used per year in the U.S. and growing rapidly.

Clay is also used as a semi-reinforcing agent for rubber. About 900 million pounds per year are used in the U.S. Most is hard clay mined in Georgia and South Carolina. It is used in tire carcasses, sidewalls and bead insulation. Clay offers some reinforcement to the rubber compound, but less than reinforcing grades of carbon black. The cost of clay is typically \$0.03 to \$0.05 per pound. Silane modified white clays are used in white sidewalls.

Ground and precipitated calcium carbonate is used in rubber compounds. The ground products are added as extender fillers, while the precipitated types offer some reinforcement due to their small particle size. It is reported that over 1 billion pounds of calcium carbonate is used in rubber compounds in the U.S. per year.

In addition to the other fillers mentioned, zinc oxide is added for cure activation, titanium dioxide is added to white sidewalls for whiteness, alumina trihydrate is used as a flame suppressant, talc is added as a filler and extrusion aid and several other mineral fillers are used for special purposes such as conductivity,
color, etc.

Fillers for Rubber Components – Non Black (2 of 2)

Issue: Almost all virgin rubber compounds (99%) utilize either carbon black or inorganic fillers such as precipitated or fumed silica, clay, ground or precipitated calcium carbonate, titanium dioxide, zinc oxide and several others as either or both reinforcing agents or extenders for rubber compounds. Recycled rubber contains the same fillers as the virgin rubber from which the recyclate was produced.

Implementation: All of the above fillers are mixed into rubber compounds. In general, more mineral fillers are used in non-tire compounds than in tire compounds. Non-black fillers are used in mats, wire and cable, footwear, rolls, hoses, belts, weather-stripping and many other types of products. The mineral fillers are added usually after the polymer in the internal mixer or on the mill. Levels commonly used are from 5 to 100 parts. Some EPODE compounds may have levels of several hundred phr for low cost materials.

Benefits: All mineral fillers are usually white or lightly colored so the obvious benefit is that non-black mineral fillers can be used to make light colored goods.

Silica is used from 10 to 15 phr in wire skim compound for steel belted tires. It increases Modulus and improves wire adhesion. In addition, it is used in many radial and passenger tire components to stiffen the compound. Silica is also used by Michelin and Goodyear in the treads of the fuel efficient low rolling resistance treads. It is used in conjunction with a polysulfidic silane coupling agent.

Clay is used in a few tire components. These include some carcasses and white sidewalls. It is used from 40 to 65 phr. Clay is extensively added to mechanical goods to lower cost and provide some reinforcement. Calcium carbonate is added to lower cost, improve processing and impart light color. It generally provides very little reinforcement or strength enhancement to the rubber.

Curing Agents and Accelerators

Issue: Almost all practical rubber compounds need to be vulcanized in order to be useful. This section will discus the common vulcanization or curing systems used for tires and some non-tire rubber products.

Best Practice: Unvulcanized rubber can be considered a high viscosity liquid which will flow under pressure. To overcome most of the flow properties, rubber requires the addition of a curing agent and chemicals to accelerate the cure. The most common curing agent is sulfur. The sulfur is thought to introduce crosslinks between the polymer chains of the rubber molecules. It is these crosslinks that make it difficult to recover the virgin rubber properties in recycled rubber and limit the use of recycled rubber in some applications. When curing rubber, heat and pressure is required to produce the crosslinks - sulfur alone requires many hours at high temperature (275-300°F) to react. Typical sulfur levels vary from 0.5 phr to 3.0 phr.

To reduce the curing time to more practical durations, organic chemicals that accelerate the cure are added. These are added at 1-2 phr levels and it is common to add a combination of accelerators to achieve the desired cure rate and properties.

It has been found when using reclaimed rubber that the levels of certain organic chemicals such as stearic acid in the original compound can be reduced. This indicates that some of the ingredients in the reclaimed material can impart properties to the virgin compound.

The most common accelerator classes and their speed or response time are shown below:

Class	Response Time	Acronyms
Aldehyde-amine	Slow	
Guanidines	Medium	DPG, DOTG
Thiazoles	Semi-Fast	MBT, MBTS
Sulfenamides	Fast-Delayed Action	CBS, TBBS, MBS, DIBS
Dithiophosphates	Fast	ZBDP
Thiurams	Very Fast	TMTD, TMTM, TETD
Tithiocarbonates	Very Fast	ZMDC, ZBDC

In addition to sulfur curing systems, some elastomers are cured with peroxides to achieve good heat resistance.

Implementation: Accelerators and curing agents are weighed accurately based on the ratio desired in the compound. They are then added into the compound using an internal mixer or two-roll mill. They are usually added late in the mix cycle to reduce the tendency to scorch or to vulcanize too quickly.

Binders, Bonding Agents, and Adhesives

Issue: In the production of virgin rubber compounds and new products it is often necessary to adhere or bond the rubber to another rubber piece, fabric or metal. This best practice describes the materials used in these applications.

Best Practice: Bonding Agents - This type is commonly used to adhere rubber to metal, plastic, and other rubber compounds. These agents are specialty prepared solvent and water based adhesives that are commonly applied to the bonding substrate. A primer is usually applied. Little is disclosed about the composition of the bonding agents.

Internal Adhesives, Bonding Agents, Binders - For metal and fiber reinforcement, such as steel belts and fabric in tires, hoses, and belts, an HRH (Hexa, Resourcinol, Hi-Sil) system is employed. This system involves adding Hexamethylene tetramine (HMT) or HMMM , resourcinol and precipitated silica into the rubber compound. This increases the stiffness of the unvulcanized rubber and the modulus of the cured rubber. The adhesion, or pull-out, force of steel or fabric from rubber is greatly enhanced with this method.

Recently, polymers with maleic anhydride modification have been introduced. EPDM, Hypalon, and PBD are currently available with this treatment. The compounds containing these modified polymers report improved adhesion.

Implementation: Bonding agents are commonly applied by spraying or painting. Internal adhesives are compounded into the virgin rubber.

Benefits: The major benefit is enhanced adhesion to metal, plastic, rubber, and other materials.

Softeners, Oils, and Plasticizers (1 of 2)

Issue: Practical rubber compounds require the incorporation of petroleum oils and plasticizers to make them processable.

Best Practice: Rubber polymers are high viscosity liquids. Inorganic fillers and carbon black are added to reinforce the rubber polymer. This increases the viscosity even further. To reduce the viscosity, improve processing and flow and reduce cost, softeners (oils and plasticizers) are added to the rubber compound. Almost all rubber compounds are softened. Levels used vary from 5-10 phr for high performance treads like aircraft and off the road tires to several hundred phr in highly oil extended EPDM hose and extruded goods.

Plasticizing oils are arbitrarily divided into aliphatic, napththenic. and aromatic classes. The most widely used class is the aromatic oil. It is commonly added to passenger and truck tire treads, carcasses, and sidewalls as well as other components. Napthtenic oils are added to white sidewalls and other components requiring non-staining properties. The recent trend in lowering the low rolling resistance of passenger tires has resulted in more napthtenic oil being used in treads and carcasses.

It should be noted that in the recycled rubber material, there is a residual oil from the original compounds in tires and non-tire products. A small amount of oil may volatize in service. However most of it is still present. In the case of truck tires, this will be mostly aromatic oil. In passenger tires this will be a blend of napthenic and aromatic oil. The aromatic oils are dark and in general staining. When added to a rubber compound the recyclate will impart staining characteristics in proportion to the amount of staining oil present.

Softeners, Oils, and Plasticizers (2 of 2)

Issue: Practical rubber compounds require the incorporation of petroleum oils and plasticizers to make them processable.

Implementation: Plasticizers and oils are added into the rubber compound as liquids, dry liquid concentrates or oil extended master batch. The liquids are most commonly used and in large rubber plants are automatically injected into the internal mixer without opening the ram.

The amount of softener or oil present is measured using the acetone extract test. This is done by refluxing the rubber with acetone and weighing the amount removed. For tires this will typically be 10-25% by weight.

Benefits: Incorporation of oils and plasticizers lowers viscosity, improves processing and extrusion properties, lowers hardness, improves low temperature flexibility and lowers cost. Proper selection of softener reduces and minimizes the loss in physical properties usually observed with their addition. Higher molecular weight oils have lower volatility and tend to be retained in the recyclate. At the present time, compounding for softeners and oils does not take into account their use in recyclates.

Rubber / Plastic Composites (1 of 2)

Issue: There is a need to find high volume applications for ground crumb or devulcanized rubber in order to increase the value of the recycling processes and to create stable, long-life markets for the materials.

Best Practice: Ground scrap rubber and devulcanized rubber could be combined with various thermoplastic materials to provide reduced-cost "green" materials without sacrificing critical properties or processing characteristics. These materials are designed to be processed on conventional thermoplastic processing equipment such as singly injection molding, screw-extrusion, or blow molding, either as combined or separate processes.

Ground rubber particles of various mesh sizes are being used to modify materials such as Linear Low-Density Polyethylene (LLDPE), Polypropylene (PP), Polyurethane (PU), and Polyvinyl Chloride (PVC) among others. Typically the rubber particles are blended at levels from 5 to 70 percent into the thermoplastic material matrix using a batch mixer or melt extrusion system (win-screw preferred) and chopped or cut into pellets suitable for further melt processing of the compounded material. A variety of rubber scrap types are used in these blends, mostly as tire buffings, cryogenically ground tires, and shoe soles buffings and scrap.

The properties of the resulting compounds depend on:
1. Mesh Size (Smaller = Stronger)
2. Elastomer Type
3. Recyclate Concentration

Recent advances in surface modification technologies of ground scrap rubber have greatly enhanced its value for use in thermoplastic compounds. Materials such as Vistamer and Ethylene-acrylic acid create more polar binding systems that allow the ground rubber blend better with the thermoplastic material, thus improving processing characteristics and material properties such as elongation and strength. These technologies open up opportunities for the compounds that until recently have been unreachable because of property deficiencies.

Devulcanized material is also finding use in thermoplastics, particularly as the soft phase when combined with PP in TPO materials. Typically, TPO materials are blends of varying ratios of PP and unvulcanized EPDM to provide toughened, higher impact resistant materials.

Rubber / Plastic Composites (2 of 2)

Issue: There is a need to find high volume applications for ground crumb or devulcanized rubber in order to increase the value of the recycling processes and to create stable, long-life markets for the materials.

Implementation: Recycled rubber or plastic compounds can be used in a variety of end-use applications such as non-engineered automotive goods (e.g., brake pedal covers, acoustic barriers), and shoes as long as the cost-to-property ratio is competitive against similar virgin materials.

Benefits: Finding a large, continuing, value-added market for recycled rubber material is one of the biggest hurdles facing recyclers today. The successful use of scrap rubber in thermoplastic compounds produces this type of market and encourages further research into the development of more applications and technologies (i.e., surface modifiers) that eventually increase the size of the market already captured by these materials.

End Product Testing Requirements

Issue: Recycled rubber finds applications in tires, hoses, belts and mats. Common tests for rubber products compounds are tensile, elongation, modulus and hardness. However, special tests are required for very specific applications. For instance, aging and heat build-up properties are a must for tire carcass compounds, and fuel resistance for automotive hoses. With the use of recycled rubber, these properties remain equally important.

Best Practice: In this best practice, examples of key test requirements for rubber products are listed below.

Products	Pertinent Tests
All rubber compounds	Mixing behavior, Mooney Viscosity
All rubber products	Tensile, modulus, elongation, hardness
Tire carcass	Heat build-up, adhesion to sidewall and belt coat compounds
Automotive hose	Fuel resistance, aging properties
Conveyor belt	Abrasion resistance, fatigue life and aging properties
Engine mounts	Dynamic properties, fatigue life, aging properties at high temperatures, compression set
Floor mats	Abrasion, discoloration

Implementation: Testing of end-products needs to be done both by recyclers and users. Processors need to know results for specific tests for pertinent applications for marketing recycled rubber. End-users need to have some idea about what to expect in items of properties by using certain percentages of recycled rubber.

Benefits: Knowledge of required critical tests will generate more meaningful test results and will avoid unnecessary tests.

Summary of Various Tests for Rubber Products

S.No.	Type	Test
1	Mixing	Mixing of rubber compounds using all necessary ingredients either in an internal mixer or on a mill in a desired time with a good band or mill after mixing.
2	Extrusion	Extrudate to have surface and edges (not feathered). (ASTM D2230)
3	Calendering	Smooth surfaces of rubber sheets when calendered in a 3-roll machine.
4	Molding	Good mold flow to fill the mold and good knitting ability of compound.
5	Mooney Viscosity	To determine viscosity of a mixed, uncured compound. This gives some idea about processability of a compound. (ASTM D4483)
6	Un-aged Tensile Strength	To determine tensile strength, elongation to break and moduli at different elongations for cured, un-aged samples. (ASTM D412)
7	Aged Tensile Strength	Same as No. 6 above except for samples following accelerated aging in hot air or any other specified aging condition. (ASTM D573)
8	Hardness	Indicates reinforcing action of a black, cured un-aged specimen, and changes in hardness due to aging for aged specimen. (ASTM D2240)
9	Pico Abrasion Test	To determine abrasion resistance of black-filled, cured compounds. (ASTM D2228)
10	Flex Fatigue Test	Determines fatigue properties of a compound, i.e. how long a compound lasts under certain fatigue conditions. (ASTM D4482)
11	Die B Teat Test	Determines tear strength of a compound (ASTM D624)
12	Heat Build-Up Test	Determines heat generation due to compression flexing. BFGoodrich Flexometer is used for this test. (ASTM D623)
13	MTS Dynamic Properties	Determines damping characteristics of a compound. Provides data on elastic modulus, loss modulus and tan δ.
14	Rubber to Rubber Adhesion	Example: How carcass compounds will adhere to belt coat compound after curing. Normally, strip adhesion test is used for this. (ASTM D429 - Rigid)
15	Fuel Resistance	How will a compound retain its properties aged in certain fuels. (ASTM D471)

Typical Rubber Reclaim (%)

Product Class	Product Type	Typical Reclaim %
Mechanical Rubber Goods	Extruded Tubing	5-10
Mechanical Rubber Goods	Weather-stripping	10-25
Mechanical Rubber Goods	Calendered Roofing Components	20-40
Mechanical Rubber Goods	Calandered Viton Sheet	10-30
Mechanical Rubber Goods	Viton Valve Stems	30-40
Mechanical Rubber Goods	Silicone Spark Plug Boots	10-30
Mechanical Rubber Goods	TPE in Brake, Clutch Pads	10-30
Mechanical Rubber Goods	Molded Roofing Components	10-30
Mechanical Rubber Goods	Automotive Shims and Spacers	60
Mechanical Rubber Goods	Railroad Crossings	0-80
Mechanical Rubber Goods	Mud Flaps	50-60
Mechanical Rubber Goods	Bed Liners	30-50
Mats	Floor Mats	10-100
Mechanical and Pharmaceutical	Crutch Tips, wheelchair Tires	10-100
Footwear	Shoe Soles	10-100

V. Standards & Specifications within the Rubber Recycling Industry (1 of 2)

Standard

A standard is a recognized technology, format or method that has been ratified by a recognized standards body.

e.g. International bodies (ISO & IEEE)
national bodies (ASTM).

Specification

Specifications have not been ratified by official bodies, but can be useful as de facto standards in the interim between identifying a need, and the relevant standard being ratified.

e.g. A company specific document which sets parameters for an item. An example of a specification would be geometric, electrical and other parameters for a specific device a specific manufacturer makes. However, a company (or other entity such as a government) may develop a specification for something such as a device or part which will be purchased. Thus, a specification may be developed for many companies as a requirement by one company (or a few companies) which is applicable to a device or part produced by any company accepting a contract.

- Standards are documents used to define acceptable conditions or behaviors and to provide a baseline for assuring that conditions or behaviors meet the acceptance criteria. In most cases, standards define *minimum* criteria; world-class quality is, by definition, beyond the standard level of performance. Standards can be written or unwritten, voluntary or mandatory. Unwritten quality standards are generally not acceptable.
- Standards educate, simplify, conserve and provide a base upon which to certify.
- In general, standards define requirements for systems, products, or processes.
- The assumption is that when a producer meets the requirements outlined in the standard, the customer can be assured of at least minimally acceptable performance.

STANDARDS

Educate	Simplify	Conserve	Provide a base upon which to certify
Standards set forth ideals or goals for the guidance of manufacturers and users alike. They are invaluable to the manufacturer who wishes to enter a new field and to the naive purchaser who wants to buy a new product	Standards reduce the number of sizes, the variety of processes, the amount of stock, and the paperwork that largely accounts for the overhead costs of making and selling	By making possible large-scale production of standard designs, standards encourage better tooling, more careful design, and more precise controls, and thereby reduce the production of defective and surplus pieces. Standards also benefit the user through lower costs.	Standards serve as hallmarks of quality which are of inestimable value to the advertiser who points to proven values, and to the buyer who sees the accredited trademark, nameplate, or label.

Organization – ASTM / ANSI

The following table depicts the standards pertaining to ASTM / ANSI. These standards are used by the rubber recycling industry.

Number	Description of Standard
ASTM D 422	Standard Test Method for Particle-Size Analysis of Soils
ASTM C 127	Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate
ASTM D5644	Standard Test Methods for Rubber Compounding Materials Determination of Particle Size Distribution of Recycled Vulcanizate Particulate Rubber
ASTM D5603	Standard Classification for Rubber Compounding Materials—Recycled Vulcanizate Particulate Rubber
ASTM D297	Standard Test Methods for Rubber Products-Chemical Analysis
ASTM D1513	Standard Test Method for Carbon Black, Pelleted - Pour Density
ASTM D2230	Standard Test Method for Rubber Property-Extrudability of Unvulcanized Compounds
ASTM D4483	Standard Practice for Evaluating Precision for Test Method Standards in the Rubber and Carbon Black Manufacturing Industries
ASTM D412	Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension
ASTM D573	Standard Test Method for Rubber - Deterioration in an Air Oven
ASTM D2240	Standard Test Method for Rubber Property - Durometer Hardness
ASTM D2228	Standard Test Method for Rubber Property-Relative Abrasion Resistance by the Pico Abrader Method
ASTM D4482	Standard Test Method for Rubber Property-Extension Cycling Fatigue
ASTM D624	Standard Test Method for Tear Strength of Conventional Vulcanized Rubber and Thermoplastic Elastomers
ASTM D623	Standard Test Methods for Rubber Property—Heat Generation and Flexing Fatigue In Compression
ASTM D429	Standard Test Methods for Rubber Property—Adhesion to Rigid Substrates
ASTM D471	Standard Test Method for Rubber Property—Effect of Liquids
ASTM C542	Standard Specification for Lock-Strip Gaskets
ASTM C864	Standard Specification for Dense Elastomeric Compression Seal Gaskets, Setting Blocks, and Spacers
ASTM D470	Standard Test Methods for Crosslinked Insulations and Jackets for Wire and Cable
ASTM D3814	Standard Guide for Locating Combustion Test Methods for Polymeric Materials
ASTM D1126	Standard Test Method for Hardness in Water
ASTM D6700	Standard Practice for Use of Scrap Tire-Derived Fuel
ASTM D6270	Standard Practice for Use of Scrap Tires in Civil Engineering Applications
ASTM F1951	Standard Specification for Determination of Accessibility of Surface Systems Under and Around Playground Equipment

Number	Description of Standard
ASTM F1487	Standard Consumer Safety Performance Specification for Playground Equipment for Public Use
CSA Z614	Children's playspaces and equipment. Includes Update No. 2.
ASTM F1292	Standard Specification for Impact Attenuation of Surface Systems Under and Around Playground Equipment
ASTM F2075	Standard Specification for Engineered Wood Fiber for Use as a Playground Safety Surface Under and Around Playground Equipment

The following table depicts the standards pertaining to ASTM / ANSI. These standards are used by the rubber recycling industry.

Number	Description of Standard
OS-10	Oil Seal Performance at Low Temperature and ASTM Test Methods, 2005
CIV-038	Symposium on Testing Soil Mixed with Waste or Recycled Materials
GEN-021	Guidelines for the Prevention and management of Scrap Tire Fires
GEN-067	Tire Pile Fires - Prevention, Response, Remediation
MOD-089	ADOT Asphalt Rubber Asphaltic Concrete Specifications
MOD-087	ADOT Asphalt Rubber Binder Specifications
MOD-088	ADOT Asphalt Rubber Mixture Design
MOD-098	ADOT Asphalt Rubber Related Specifications
MOD-092	Caltrans Type G Specifications
MOD-093	Caltrans Type O Specifications
MOD-042	Caltrans Warrantee Specifications for Pilot Projects
PRO-008	Standard Test Method for Rubber Compounding Materials - Recycled Vulcanizate Particulate Rubber
PRO-007	Standard Test method for Rubber Materials - Determination of Part Size Distribution of Recycled Vulcanized Particulate Rubber

ASTM F1951-09b – ADA Compliance

Description: Standard Specification for Determination of Accessibility of Surface Systems Under and Around Playground Equipment

Summary:

1.1 This specification establishes minimum characteristics for those factors that determine accessibility. This specification applies to all types of materials that can be used under and around playground equipment.

1.2 The material under and around playground equipment that meets this specification must also comply with Specification F 1292 if the surface is within the fall zone.

1.3 This specification does not imply that an injury cannot be incurred if the surface system complies with this specification.

1.4 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard. (See ASTM SI10.)

1.5 The following precautionary statement pertains only to the test method portions, Sections 6 and 7, of this specification: This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

ASTM D422-63 (2007) – Particle Size

Description: Standard Test Method for Particle-Size Analysis of Soils

Summary:

1.1 This test method covers the quantitative determination of the distribution of particle sizes in soils. The distribution of particle sizes larger than 75 µm (retained on the No. 200 sieve) is determined by sieving, while the distribution of particle sizes smaller than 75 µm is determined by a sedimentation process, using a hydrometer to secure the necessary data (Note 1 and Note 2).

Note 1
Separation may be made on the No. 4 (4.75-mm), No. 40 (425-m), or No. 200 (75-m) sieve instead of the No. 10. For whatever sieve used, the size shall be indicated in the report.

Note 2
Two types of dispersion devices are provided: (1) a high-speed mechanical stirrer, and (2) air dispersion. Extensive investigations indicate that air-dispersion devices produce a more positive dispersion of plastic soils below the 20-m size and appreciably less degradation on all sizes when used with sandy soils. Because of the definite advantages favoring air dispersion, its use is recommended. The results from the two types of devices differ in magnitude, depending upon soil type, leading to marked differences in particle size distribution, especially for sizes finer than 20 m.

ASTM C127-07 – Density and Absorption

Description: Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate

Summary:

1.1 This test method covers the determination of the average density of a quantity of coarse aggregate particles (not including the volume of voids between the particles), the relative density (specific gravity), and the absorption of the coarse aggregate. Depending on the procedure used, the density (kg/m3 (lb/ft3)) is expressed as oven-dry (OD), saturated-surface-dry (SSD), or as apparent density. Likewise, relative density (specific gravity), a dimensionless quantity, is expressed as OD, SSD, or as apparent relative density (apparent specific gravity). The OD density and OD relative density are determined after drying the aggregate. The SSD density, SSD relative density, and absorption are determined after soaking the aggregate in water for a prescribed duration.

1.2 This test method is used to determine the density of the essentially solid portion of a large number of aggregate particles and provides an average value representing the sample. Distinction is made between the density of aggregate particles as determined by this test method, and the bulk density of aggregates as determined by Test Method C 29/C 29M, which includes the volume of voids between the particles of aggregates.

1.3 This test method is not intended to be used with lightweight aggregates.

1.4 The values stated in SI units are to be regarded as the standard for conducting the tests. The test results for density shall be reported in either SI units or inch-pound units, as appropriate for the use to be made of the results.

1.5 The text of this test method references notes and footnotes which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of this test method.

ASTM F1487-07ae1 – Consumer Safety Performance

Description: Standard Consumer Safety Performance Specification for Playground Equipment for Public Use

Summary:

1.1 This consumer safety performance specification provides safety and performance standards for various types of public playground equipment. Its purpose is to reduce life-threatening and debilitating injuries.

1.2 The range of users encompassed by this consumer safety performance specification is the 5th percentile 2-year-old through the 95th percentile 12-year-old.

1.3 Home playground equipment, toys, amusement rides, sports equipment, fitness equipment intended for users over the age of 12, public use play equipment for children 6 to 24 months, and soft contained play equipment are not included in this specification.

1.4 Products or materials (site furnishings) that are installed outside the equipment use zone, such as benches, tables, and borders, used to contain protective surfacing, are not considered playground equipment and are not included in this specification.

1.5 This specification does not address accessibility, except as it pertains to safety issues not covered in the Americans with Disabilities Act Accessibility Guidelines (ADAAG).

ASTM F1292-04 – Impact Attenuation/Fall Height Test

Description: Standard Specification for Impact Attenuation of Surface Systems Under and Around Playground Equipment

Summary:

1.1 This specification establishes minimum performance requirements for the impact attenuation of playground surfacing materials installed within the use zone of playground equipment.

1.2 This specification is specific to surfacing used in conjunction with playground equipment, such as that described in Specifications F 1148, F 1487, F 1918, F 1951, and F 2075.

1.3 This specification establishes an impact attenuation performance criterion for playground surfacing materials; expressed as a critical fall height.

1.4 This specification establishes procedures for determining the critical fall height of playground surfacing materials under laboratory conditions. The laboratory test is mandatory for surfaces to conform to the requirements of this specification.

1.5 The laboratory test required by this specification addresses the performance of dry surfacing materials.

1.6 The critical fall height of a playground surfacing material determined under laboratory conditions does not account for important factors that may influence the actual performance of installed surfacing materials. Factors that are known to affect surfacing material performance include but are not limited to aging, moisture, maintenance, exposure to temperature extremes (for example, freezing), exposure to ultraviolet light, contamination with other materials, compaction, loss of thickness, shrinkage, submersion in water, and so forth.

ASTM F2075-04e1 – IPEMA

Description: Standard Specification for Engineered Wood Fiber for Use as a Playground Safety Surface Under and Around Playground Equipment

Summary:

1.1 This specification establishes minimum characteristics for those factors that determine particle size, consistency, purity, and ability to drain.

1.2 Engineered wood fiber that meets the requirements of this specification must comply with Specification F 1292, if the surface is in the use zone as defined in Specification F 1487.

1.3 A sample of wood fiber that meets the requirements of this specification may be designated engineered wood fiber and be suitable for playground safety surfacing.

1.4 This specification does not imply that an injury cannot be incurred if the engineered wood fiber complies with this specification.

1.5 To meet the requirements of this specification, the material shall perform as follows:
- 1.5.1 The material shall meet particle size requirements.
- 1.5.2 The material shall meet the requirement for metal particles.
- 1.5.3 The material shall meet the allowable heavy metal concentrations considered hazardous to children.
- 1.5.4 The material shall meet the requirements of Specification F 1292.

ASTM D5644-01(2008) – Particle Size Distribution

Description: Standard Test Methods for Rubber Compounding Materials Determination of Particle Size Distribution of Recycled Vulcanizate Particulate Rubber

Summary:

1.1 These test methods describe the procedures for determining average particle size distribution of recycled vulcanizate particulate.

1.2 Method A describes the Ro-tap sieve test method for 60 mesh or coarser particles.

1.3 Method B describes the ultrasonic technique combined with optical microscope especially suitable for 80 mesh or finer particles. This procedure is based on Test Method D 3849.

1.4 The values stated in SI units are to be regarded as the standard.

1.5 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

ASTM D5603-01(2008) – Rubber Compounding Material

Description: Standard Classification for Rubber Compounding Materials—Recycled Vulcanizate Particulate Rubber

Summary:

1.1 This classification covers the compounding material commercially known as recycled vulcanizate particulate rubber. Recycled vulcanizate particulate rubber is the product that results when vulcanizate rubber has been processed by some means to obtain a desired particle size distribution.

1.2 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.3 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

ASTM D297-93(2006) – Chemical Analysis

Description: Standard Test Methods for Rubber Products-Chemical Analysis

Summary:

1.1 These test methods cover the qualitative and quantitative analysis of the composition of rubber products of the "R" family. Many of these test methods may be applied to the analysis of natural and synthetic crude rubbers.

1.1.1 Part A consists of general test methods for use in the determination of some or all of the major constituents of a rubber product.

1.1.2 Part B covers the determination of specific polymers present in a rubber product.

ASTM D1513-05 – Pour Density

Description: Standard Test Method for Carbon Black, Pelleted - Pour Density

Summary:

1.1 This test method covers the determination of the pour density of pelleted carbon blacks.

1.2 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.3 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

ASTM D2230-96(2007) - Extrudability

Description: Standard Test Method for Rubber Property-Extrudability of Unvulcanized Compounds

Summary:

1.1 This test method covers the determination of the extrudability of unvulcanized SBR and NBR rubber compounds through a screw-type extruder equipped with ASTM Extrusion Die, Garvey type. This test method is designed to allow the observation of the appearance and contours of the extrusion. Rating systems are provided along with recipes for compounds of known extrusion characteristics. The utility of the test method for evaluating rubbers or compounding materials other than those listed has not been established. Since extrusion machines differ among laboratories, the procedure includes techniques that minimize differences between machines.

1.2 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.3 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

ASTM D4483-05a – Precision Evaluation

Description: Standard Practice for Evaluating Precision for Test Method Standards in the Rubber and Carbon Black Manufacturing Industries

Summary:

1.1 This practice covers guidelines for evaluating precision and serves as the governing practice for inter laboratory test programs (ITP) used to evaluate precision for test methods as used in the rubber manufacturing and the carbon black industries. This practice uses the basic one way analysis of variance calculation algorithms of Practice E 691. Although bias is not evaluated in this practice, it is an essential concept in understanding precision evaluation.

1.2 This practice applies to test methods that have test results expressed in terms of a quantitative continuous variable. Although exceptions may occur, it is in general limited to test methods that are fully developed and in routine use in a number of laboratories.

1.3 Two precision evaluation methods are given that are described as *robust statistical* procedures that attempt to eliminate or substantially decrease the influence of outliers. The first is a *General Precision* procedure intended for all test methods in the rubber manufacturing industry, and the second is a specific variation of the general precision procedure designated as *Special Precision*, that applies to carbon black testing. Both of these procedures use the same uniform level experimental design and the Mandel *h* and *k* statistics to review the precision database for potential outliers. However, they use slight modifications in the procedure for rejecting incompatible data values as outliers. The *Special Precision* procedure is specific as to the number of replicates per database cell or material-laboratory combination.

ASTM D412-06ae2 – Evaluation of Tensile Properties

Description: Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension

Summary:

1.1 These test methods cover procedures used to evaluate the tensile (tension) properties of vulcanized thermoset rubbers and thermoplastic elastomers. These methods are not applicable to ebonite and similar hard, low elongation materials. The methods appear as follows:

Test Method A—Dumbbell and Straight Section Specimens
Test Method B—Cut Ring Specimens

Note 1—These two different methods do not produce identical results.

1.2 The values stated in either SI or non-SI units shall be regarded separately as normative for this standard. The values in each system may not be exact equivalents; therefore each system must be used independently, without combining values.

1.3 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

ASTM D573-04 – Influence of Elevated Temperature

Description: Standard Test Method for Rubber - Deterioration in an Air Oven

Summary:

1.1 This test method covers a procedure to determine the influence of elevated temperature on the physical properties of vulcanized rubber. The results of this test method may not give an exact correlation with service performance since performance conditions vary widely. This test method may, however, be used to evaluate rubber compounds on a laboratory comparison basis.

1.2 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.3 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

ASTM D2240-05 – Durometer Hardness

Description: Standard Test Method for Rubber Property - Durometer Hardness

Summary:

1.1 This test method covers twelve types of rubber hardness measurement devices known as durometers: Types A, B, C, D, DO, E, M, O, OO, OOO, OOO-S, and R. The procedure for determining indentation hardness of substances classified as thermoplastic elastomers, vulcanized (thermoset) rubber, elastomeric materials, cellular materials, gel-like materials, and some plastics is also described.

1.2 This test method is not equivalent to other indentation hardness methods and instrument types, specifically those described in Test Method D 1415.

1.3 This test method is not applicable to the testing of coated fabrics.

1.4 All materials, instruments, or equipment used for the determination of mass, force, or dimension shall have traceability to the National Institute for Standards and Technology, or other internationally recognized organizations parallel in nature.

1.5 The values stated in SI units are to be regarded as standard. The values given in parentheses are for information only. Many of the stated dimensions in SI are direct conversions from the U.S. Customary System to accommodate the instrumentation, practices, and procedures that existed prior to the Metric Conversion Act of 1975.

1.6 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

ASTM D2228-04(2009) – Abrasion Resistance

Description: Standard Test Method for Rubber Property-Relative Abrasion Resistance by the Pico Abrader Method

Summary:

1.1 This test method covers the determination of the abrasion resistance of vulcanized (thermoset) rubbers, thermoplastic elastomers, and elastomeric and similar materials to a standardized reference system. A standardized set of reference compounds is used to calculate relative abrasion resistance. These reference compounds are also used to determine the relative performance, within a permissible range, of the cutting knives used in performing the test.

1.2 All materials, instruments, or equipment used for the determination of mass, force, or dimension shall have traceability to the National Institute for Standards and Technology, or other internationally recognized organization parallel in nature.

1.3 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.4 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

ASTM D4482-07 – Fatigue Life

Description: Standard Test Method for Rubber Property-Extension Cycling Fatigue

Summary:

1.1 This test method covers the determination of fatigue life of rubber compounds undergoing a tensile-strain cycle. During part of the cycle, the strain is relaxed to a zero value. The specimens are tested without intentionally initiated flaws, cuts, or cracks. Failure is indicated by a complete rupture of the test specimen.

1.2 No exact correlation between these test results and service is given or implied. This is due to the varied nature of service conditions. These test procedures do yield data that can be used for the comparative evaluation of rubber compounds for their ability to resist (dynamic) extension cycling fatigue.

1.3 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.4 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

ASTM D624-00(2007) – Tear Strength

Description: Standard Test Method for Tear Strength of Conventional Vulcanized Rubber and Thermoplastic Elastomers

Summary:

1.1 This test method describes procedures for measuring a property of conventional vulcanized rubber and thermoplastic elastomers called tear strength.

1.2 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.3 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

ASTM D623-07 – Fatigue Characteristics and Heat Generation

Description: Standard Test Methods for Rubber Property—Heat Generation and Flexing Fatigue In Compression

Summary:

1.1 These test methods may be used to compare the fatigue characteristics and rate of heat generation of different rubber vulcanizates when they are subjected to dynamic compressive strains.

1.2 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.3 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

ASTM D429-08 – Adhesion to Rigid Substrates

Description: Standard Test Methods for Rubber Property—Adhesion to Rigid Substrates

Summary:

1.1 These test methods cover procedures for testing the static adhesional strength of rubber to rigid materials (in most cases metals).

Method A—Rubber Part Assembled Between Two Parallel Metal Plates
Method B—90° Stripping Test—Rubber Part Assembled to One Metal Plate
Method C—Measuring Adhesion of Rubber to Metal with a Conical Specimen
Method D—Adhesion Test—Post-Vulcanization (PV) Bonding of Rubber to Metal
Method E—90° Stripping Test—Rubber Tank Lining—Assembled to One Metal Plate
Method F—Rubber Part Assembled Between Two Parallel Convex-Shaped Metal Plates
Method G—Measuring Bond Durability for Rubber-to-Metal Bonded Components with a Double Shear Cylindrical Specimen
Method H—Measuring Bond Durability for Rubber-to-Metal Bonded Components with a Quadruple Shear Specimen

1.2 While the test method may be used with a wide variety of rigid materials, use of materials other than metals is the exception. For this reason, we have used the word "metal" in the text rather than "rigid materials."

1.3 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.4 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

ASTM D471-06e1 – Effect of Liquids

Description: Standard Test Method for Rubber Property—Effect of Liquids

Summary:

1.1 This test method covers the required procedures to evaluate the comparative ability of rubber and rubber-like compositions to withstand the effect of liquids. It is designed for testing: (1) specimens of vulcanized rubber cut from standard sheets (see Practice D 3182), (2) specimens cut from fabric coated with vulcanized rubber (see Test Methods D 751), or (3) finished articles of commerce (see Practice D 3183). This test method is not applicable to the testing of cellular rubbers, porous compositions, and compressed sheet packing, except as described in 11.2.2.

1.2 ASTM Oils No. 2 and No. 3, formerly used in this test method as standard test liquids, are no longer commercially available and in 1993 were replaced with IRM 902 and IRM 903, respectively.

1.3 ASTM No. 1 Oil, previously used in this test method as a standard test liquid, is no longer commercially available and in 2005 was replaced with IRM 901; refer to Table 1, Footnote A, and Appendix X3 for details.

1.4 This test method includes the following:
Change in Mass (after immersion) - Section 10
Change in Volume (after immersion) - Section 11
Dimensional-Change Method for Water-Insoluble Liquids and Mixed Liquids - Section 12
Change in Mass with Liquid on One Surface Only - Section 13
Determining Mass of Soluble Matter Extracted by the Liquid - Section 14
Change in Tensile Strength, Elongation and Hardness (after immersion) - Section 15
Change in Breaking Resistance, Burst Strength, Tear Strength and Adhesion for Coated Fabrics - Section 16
Calculation (of test results) - Section 18

ASTM C542-05 – Lock-Strip Gaskets

Description: Standard Specification for Lock-Strip Gaskets

Summary:

1.1 This specification defines the required properties of lock-strip gaskets where resistance to sunlight, weathering, flame, oxidation, permanent deformation under load, and diminution of gripping pressure are prime essentials.
Note 1—The requirement of flame propagation may be waived by the architect or professional engineer when doing so does not conflict with local codes or ordinances.

1.2 This specification applies only to the "locking" compression type of gasket, sometimes referred to as the "zipper" type.
Note 2—Structural integrity and weather-tightness of the wall requires the sound design and installation of the entire system of which the gasket is only one component.

1.3 The values stated in SI units are to be regarded as the standard.

1.4 Test Method C 1166, as referenced in this specification, should be used to measure and describe the properties of materials, products, or assemblies in response to heat and flame under controlled laboratory conditions and should not be used to describe or appraise the fire hazard or fire risk of materials, products, or assemblies under actual fire conditions. However, results of this test may be used as elements of a fire risk assessment which takes into account all of the factors which are pertinent to an assessment of the fire hazard of a particular end use.

ASTM C864-05 – Dense Elastomeric Compression

Description: Standard Specification for Dense Elastomeric Compression Seal Gaskets, Setting Blocks, and Spacers

Summary:

1.1 This specification covers preformed dense elastomeric compression gaskets and accessories for use in sealing and glazing applications. These materials are generally used to seal or serve as components of compression sealing systems between mechanically restrained surfaces in building constructions.

1.2 Test Method C 1166, as referenced in this specification, should be used to measure and describe the properties of materials, products, or assemblies in response to heat and flame under controlled laboratory conditions and should not be used to describe or appraise the fire hazard or fire risk of materials, products, or assemblies under actual fire conditions. However, results of this test may be used as elements of a fire risk assessment which takes into account all of the factors which are pertinent to an assessment of the fire hazard of a particular end use.

ASTM D470-05 – Crosslinked Insulations

Description: Standard Test Methods for Crosslinked Insulations and Jackets for Wire and Cable

Summary:

1.1 These test methods cover procedures for testing crosslinked insulations and jackets for wire and cable. To determine the test to be made on the particular insulation or jacket, refer to the product specification for that type. These test methods do not apply to the class of products known as flexible cords.

1.2 Whenever two sets of values are presented, in different units, the values in the first set are the standard, while those in the parentheses are for information only.

1.3 In many instances the insulation or jacket cannot be tested unless it has been formed around a conductor or cable. Therefore, tests are done on insulated or jacketed wire or cable in these test methods solely to determine the relevant property of the insulation or jacket and not to test the conductor or completed cable.

1.4 The procedures appear in the following sections.

1.5 This test applies to the detection and measurement of partial discharges occurring in the following types of electric cables:
- 1.5.1 Single-conductor shielded cables and assemblies thereof, and
- 1.5.2 Multiple-conductor cables with individually shielded conductors.

1.6 Do not perform these tests on:
- 1.6.1 Cables which have a nonconductive separator between the conductor and the insulation,
- 1.6.2 Cables having insulations less than 0.045 in. (1.14 mm) thick, or
- 1.6.3 Insulations with coverings that are not removable without damage to the insulation.

ASTM D3814-06 – Locating Combustion Test Methods

Description: Standard Guide for Locating Combustion Test Methods for Polymeric Materials

Summary:

1.1 This guide provides assistance in locating test methods and related documents for determining the combustion properties of polymeric materials used for various applications.

1.2 This guide includes standardized North American and global test methods promulgated by ASTM, CSA, NFPA, SAE, Underwriters Laboratories, North American Government Agencies, IEC, and ISO. It does not include industrial tests, user specification tests, nor nonstandard test methods. This list of tests is not exhaustive and the user must assume other tests may exist for specific materials or applications.

1.3 This guide is arranged according to products and systems.

1.4 The test methods described in this guide should be used solely to measure and describe the properties of materials, products, or systems in response to heat and flame under controlled laboratory conditions and should not be considered or used for the description, appraisal, or regulation of the fire hazard of materials, products, or systems under actual fire conditions.

ASTM D1126-02(2007)e1 – Hardness in Water

Description: Standard Test Method for Hardness in Water

Summary:

1.1 This test method covers the determination of hardness in water by titration. This test method is applicable to waters that are clear in appearance and free of chemicals that will complex calcium or magnesium. The lower detection limit of this test method is approximately 2 to 5 mg/L as $CaCO_3$; the upper limit can be extended to all concentrations by sample dilution. It is possible to differentiate between hardness due to calcium ions and that due to magnesium ions by this test method.

1.2 This test method was tested on reagent water only. It is the user's responsibility to ensure the validity of the test method for waters of untested matrices.

ASTM D6700-01(2006) – TDF Applications

Description: Standard Practice for Use of Scrap Tire-Derived Fuel

Summary:

1.1 This practice covers and provides guidance for the material recovery of scrap tires for their fuel value. The conversion of a whole scrap tire into a chipped formed for use as a fuel produces a product called tire-derived fuel (TDF). This recovery practice has moved from a pioneering concept in the early 1980s to a proven and continuous use in the United States with industrial and utility applications.

1.2 Combustion units engineered to use solid fuels, such as coal or wood or both, are fairly numerous throughout the U.S. Many of these units are now using TDF even though they were not specifically designed to burn TDF. It is clear that TDF has combustion characteristics similar to other carbon-based solid fuels. Similarities led to pragmatic testing in existing combustion units. Successful testing led to subsequent acceptance of TDF as a supplemental fuel when blended with conventional fuels in existing combustion devices. Changes required to modify appropriate existing combustion units to accommodate TDF range from none to relatively minor. The issues of proper applications and specifications are critical to successful utilization of this alternative energy resource.

1.3 This practice explains TDF's use when blended and combusted under normal operating conditions with originally specified fuels. Whole tire combustion for energy recovery is not discussed herein since whole tire usage does not require tire processing to a defined fuel specification.

1.4 This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

ASTM D6270-08e1 – Civil Engineering Applications

Description: Standard Practice for Use of Scrap Tires in Civil Engineering Applications

Summary:

1.1 This practice provides guidance for testing the physical properties, design considerations, construction practices, and leachate generation potential of processed or whole scrap tires in lieu of conventional civil engineering materials, such as stone, gravel, soil, sand, lightweight aggregate, or other fill materials.

1.2 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

VI. Why have Recycled Rubber Products not gained traction in the market? (1 of 2)

- Safety Issues

  Over several years, recycled rubber products have been under high scrutiny over their safety. Poor manufacturing processes and dismal QA/QC practices have maligned the image of post-recycled rubber products. Several incidents and occurrences (that could have been easily controlled) in the past have developed an ‘unsafe’ perception of post-recycled products in minds of many consumers.

  “Questions have arisen over whether recycled rubber products pose health risks to children. Such speculations will potentially curb the demand for post-recycled rubber products. New York City, for example, has decided that its new sports fields will no longer use tire crumb. A published report on Thursday said the EPA is reconsidering its endorsement of the use of ground-up tires in playgrounds and sports fields, based on concerns raised by the agency’s own scientists.”

  - Business Today, The Buffalo News, June 05, 2009

  “In spring 2008, New Jersey officials found elevated lead levels in some older artificial fields; a number were closed. In September, the California Attorney General's Office sued three turf manufacturers because they "failed to provide clear and reasonable warnings" that their products contained lead, a violation of state law. The case remains open.”

  - USAToday, June 10, 2009

- Physical and Chemical Properties

  It is perceived that the lack of physical properties of virgin rubber and poor chemical bonding in recycled rubber make recycled rubber a difficult alternative to replace products made out of virgin rubber

- Incentive/Funding Issues

  Lack of proper incentives (such as rebates) in the purchase/adoption of post-recycled rubber products encourages many buyers to continue using virgin rubber products that can be easily replaced with recycled rubber products. This results in either a drop in demand or stagnant market for recycled rubber products.

VI. Why have Recycled Rubber Products still not gained traction in the market? (2 of 2)

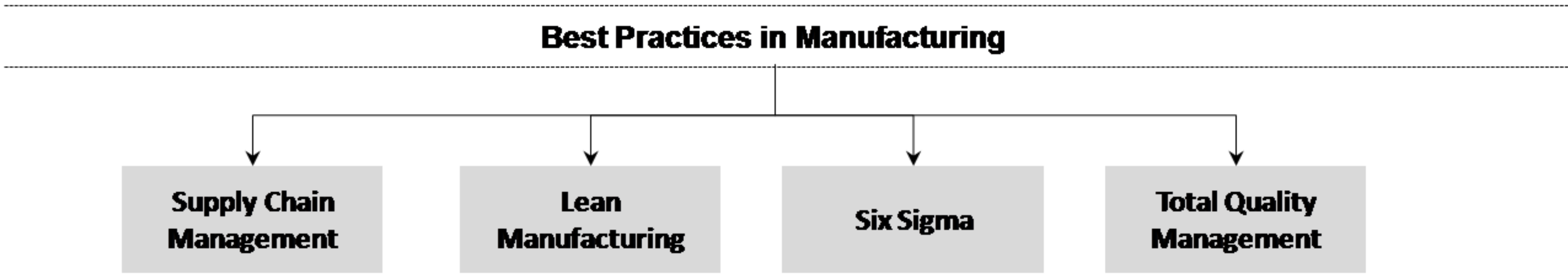
- Lack of ‘Uniform’ Industry Standards & Specifications
- It is estimated that the addition of crumb rubber to a virgin rubber compound will reduce the physical properties of the new compound by 10% - 15%
- In some cases, failure to comply with ADA (American Disabilities Act) requirements
- Lack of significant media support
- Allowing the escalation of negative consumer perception about recycled products
- Conservative one-dimensional approach taken by incumbent rubber recycling businesses is prohibiting these businesses from expanding into the virgin rubber market
- Lack of access to better technological infrastructure
- Noticeable product issues such as smell, appearance, performance and dimensional stability compared to virgin rubber products
- Lack of awareness of market potential among the rubber recyclers
- High cost to adhere to standards required by the products that are made of virgin rubber and that can be replaced by recycled rubber
- High export volume to overseas leaves less material in the domestic market that can be used to replace recycled rubber products
- Lack of knowledge sharing within the industry
- Current low price of virgin rubber is a market barrier for recycled rubber products

Certain tests have shown that when post-recycled rubber is treated with an agent such as Tricycle® and incorporated at acceptable levels, the physical properties of this new compound exhibit extremely high retention (92.8% of original tensile strength) of original values of that of a comparable 100% virgin EPDM.

It is estimated that a significant percent of current virgin rubber based products can be replaced by recycled rubber products.

VII. Best Practices

- While there are several best practices that exist and are followed, we are focusing on the following four best practices. These high-impact practices have been successfully adopted by a multitude of businesses ranging from small to large. Over a period of time, these best practices have helped businesses improve the quality of their products and services, saved millions (in several cases billions) of dollars, improved safety, decreased the lead times, improved customer perception and goodwill, and have also provided opportunity to develop new products and services.



Supply Chain Management (SCM)

- What is Supply Chain?
  - Supply Chain (SC) is a coordinated system of organizations, people, activities, information and resources involved in moving a product or service in physical or virtual manner from supplier to customer.

- What is Supply Chain Management?
  - Supply Chain Management (SCM) is the management of the entire value-added chain, from the supplier to manufacturer right through to the retailer and the final customer. It incorporates the process of planning, implementing, and controlling the operations of the supply chain with the purpose of satisfying customer requirements as efficiently as possible.

- What is Supply Chain Strategy?
  - SC Strategy is the process that defines how the supply chain should operate in order to compete. It's a process that constitutes the actual operations of that organization and the extended supply chain to meet a specific supply chain objective. It's a process that evaluates benefit trade-offs or operational components. SC strategy is broader and includes the formulation of SCM.

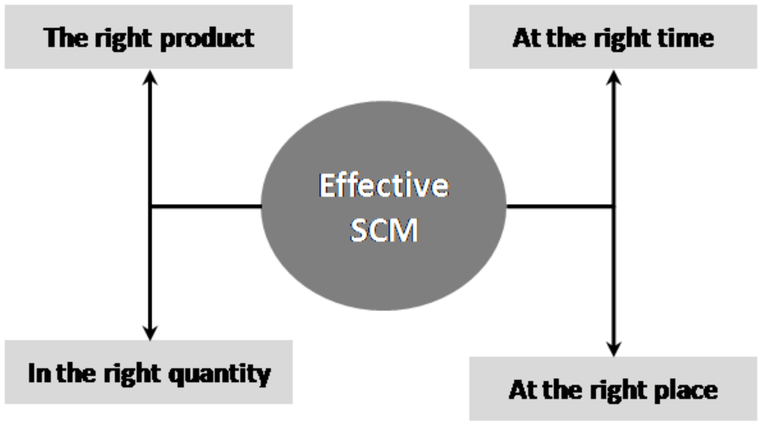
Example of a generic Supply Chain

What is Effective SCM

What does effective SCM do?

Effective SCM

- Aligns the business goals with operational components within the existing supply chain
- Develops effective production and delivery mechanisms
- Helps develop processes that can produce goods to the actual end-user rate of demand for the smallest time-period manageable
- Ensures that the variety of products reaching the market place matches what customers want to buy



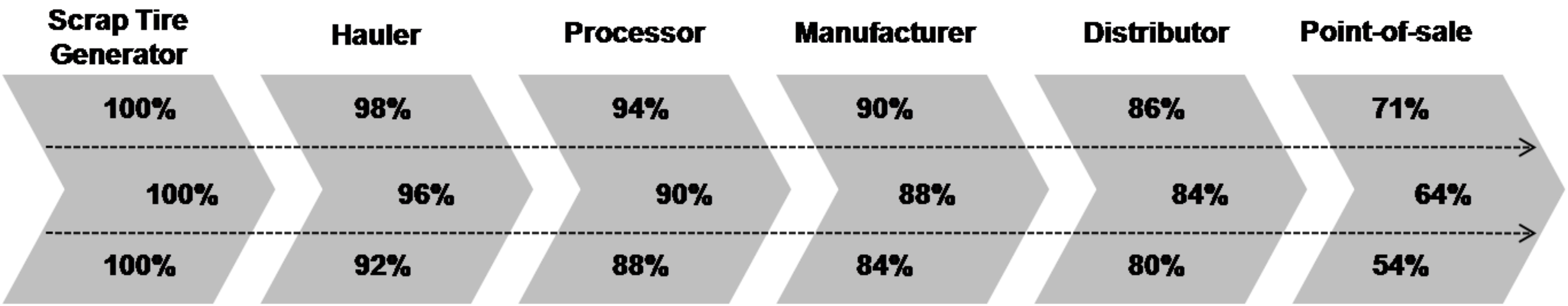
According to a research by Gartner Group, as part of effective SCM practices, enterprises that implement strategic supply-chain planning along with a continuous improvement program are likely to increase ROI by 40% during a five-year lifecycle.

Supply Chain Management

- Supply Chain Quality
  - Recalls are costing businesses billions of dollars annually, and manufacturers simply cannot afford to gamble with quality control. When manufacturers rely so heavily on the supply chain to deliver quality materials, measuring and controlling these products in real-time, before they are purchased and shipped becomes imperative. As the supply chain is playing an increasingly prominent role in business vitality, manufacturers have been incorporating supplier rating systems that provide greater transparency into their quality records. While some organizations rely strictly upon supplier certificates of analysis (COA's) or some internal supplier rating score to manage their suppliers, there is often a discrepancy with the actual findings at incoming inspections. While incoming inspections can usually detect problems before additional steps occur, they are time-consuming, costly, and performed after-the-fact.
  - A much more efficient way of managing supplier quality is to do so while the products are being manufactured on the supplier's plant floor. Using collaborative technology to facilitate the communication and share data in real-time, manufacturers and their suppliers can work together to ensure that the products meet specifications prior to being purchased and delivered. Additionally, when working with multiple suppliers of the same product, manufacturers who have access to supplier quality data can evaluate the various vendors and can scientifically determine the highest quality suppliers.

- Supply Chain Collaboration
  - Investing the time and money on stringent quality control procedures and standards internally will only go so far in preventing defects from supplied products. If supplied materials and components are not meeting standards and are being sent back, or actually incorporated into the final product, even the most capable manufacturing facilities are operating inefficiently. When manufacturers and their suppliers apply the scientific methodology of real-time Statistical Process Control (SPC), manufacturers can methodically improve the quality of incoming materials. By collecting and analyzing supplier shop floor data in real-time – and by receiving instant alarms – manufacturers have the ability to collaborate with their suppliers to immediately help them identify and resolve quality issues before they become quality problems.
  - Forward-thinking manufacturers realize that the supply chain is playing an increasingly prominent role in business vitality and have incorporated modern technologies into their quality management strategy.

Supply Chain Management
Impact of Quality in the Recycled Rubber Supply Chain



Activities that reduce quality are:
- Poor selection
- Bad categorization
- Bad inspections

Key metrics include:
- Conveyance per tire
- Unscheduled pickups
- LTLs

Activities that reduce quality are:
- Supplier quality
- Changeovers
- No Standard work
- Material flow
- No Preventative maintenance

Key metrics include:
- Repetitive processing or rework
- QC failure rate
- Returns

Activities that reduce quality are:
- Supplier quality
- Changeovers
- No Standard work
- Material flow
- No Preventative maintenance

Key metrics include:
- First pass yield
- % returns
- Fulfillment rate
- On-time delivery
- Repetitive handling

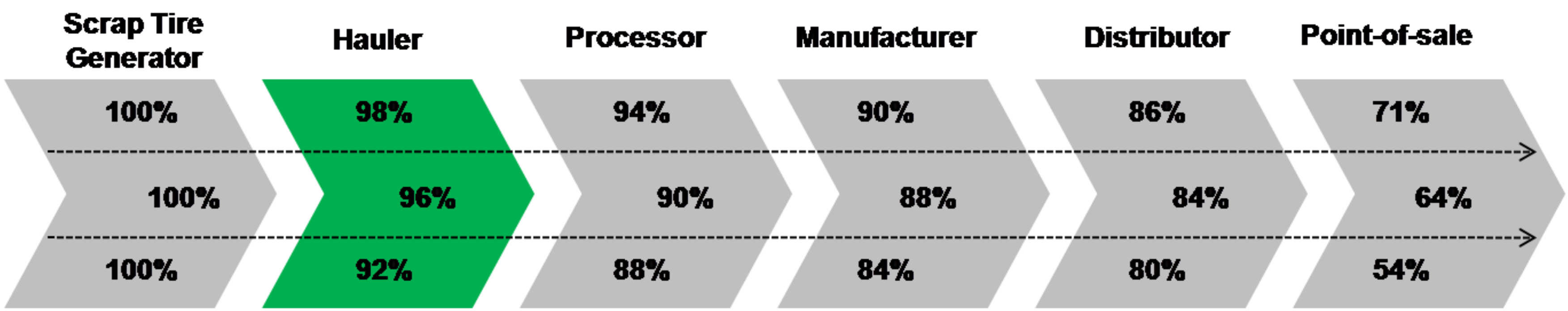
Activities that reduce quality are:
- Improper loading
- Improper packaging
- Lack of Automation
- Repetitive conveyance

Key metrics include:
- Handling Damage
- Service claims (tickets)
- On-time delivery

Activities that reduce quality are:
- Poor quality materials
- Mishandling
- Improper storage
- No product-specific training

Key metrics include:
- Customer returns
- Warranty claims
- Loss of account or customer

Supply Chain Management – Hauler



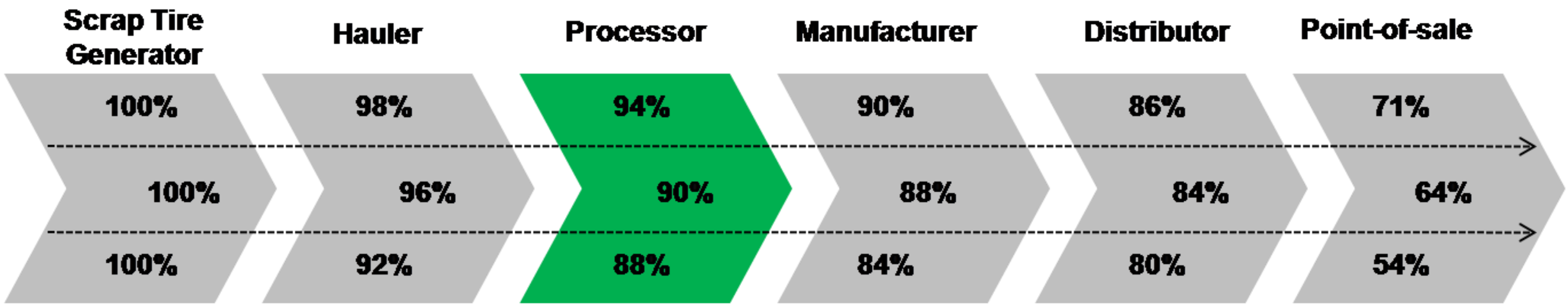
Activities that would reduce quality are:

Poor selection → Would not get yield in product → Process more to get the same amount of yield → Excessive processing
Bad categorization → Loss of revenue
Bad inspections → mixed output → rework → non value added time

Key metrics include:

Conveyance per tire	Unscheduled pickups	LTLs
•Number of runs per day/week/month	•Number of unscheduled pickups per period •Cost of unscheduled pickups	•Number of LTLs per day/week/month •paid per tire

Supply Chain Management – Processor



Activities that would reduce quality are:

Supplier quality → Various types of tires → Significant variance in characteristics and quality of output

Changeovers → Unnecessary wear and tear of tools → Undesired product → Lot of time spent to rework

No Standard work → Multiple ways of accomplishing the same task → Excessive waste of man and machine hours

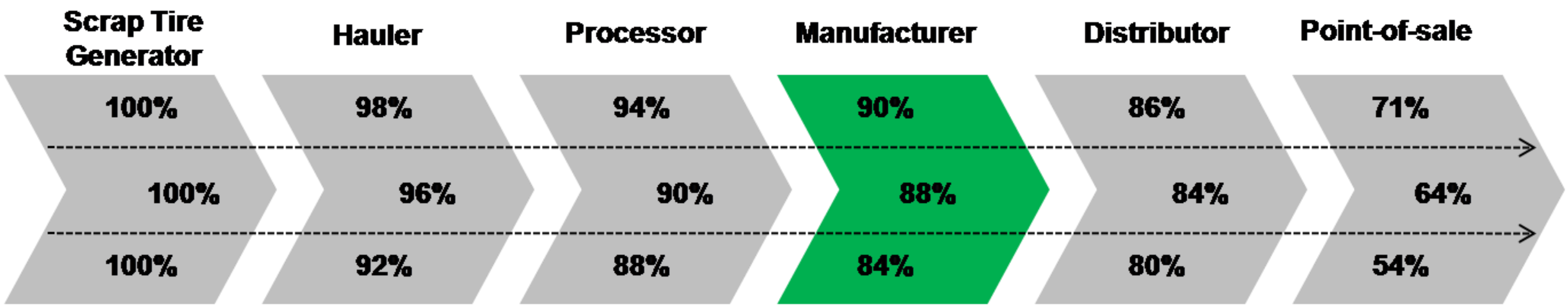
Material flow → Excessive transportation → Excess inventory → Excess space requirements → Excessive costs

No Preventative maintenance → Unplanned downtime → Frequent breakdowns → Late deliveries → Unhappy customer

Key metrics include:

Repetitive processing or rework	QC failure rate	Returns
•Number of re-runs per batch	•DPMO •First Pass Yield •OEE •Cost of unscheduled pickups	•Number of returns per month •Value ($) of returns per month •Returns per manufacturer per month

Supply Chain Management - Manufacturer



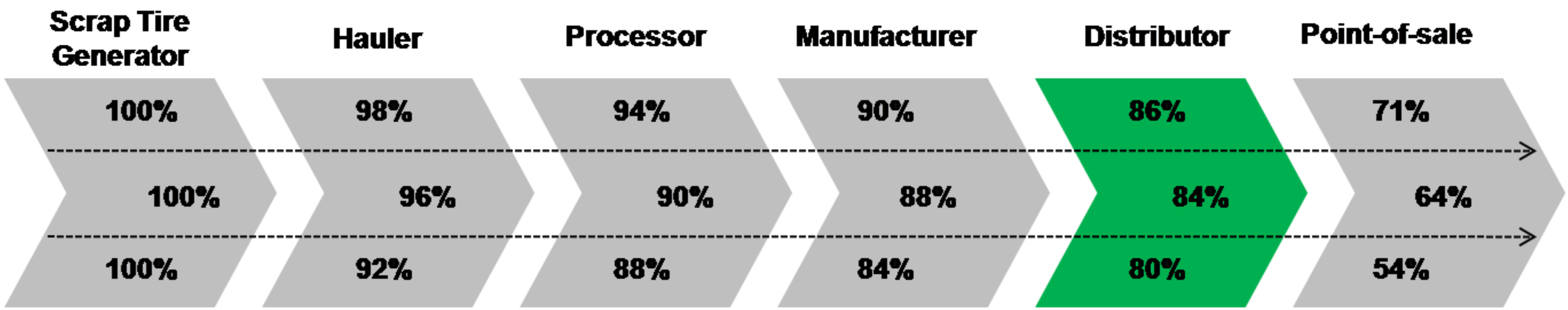
Activities that would reduce quality are:

Supplier quality → Excessive incoming inspection → Downtime → rework → Poor on-time delivery
Changeovers → Downtime → Reduced productivity
No Standard work → Multiple ways of accomplishing the same task → Excessive waste of man and machine hours
Material flow → Excessive transportation → Excess inventory → Excess space requirements → Excessive costs
No preventative maintenance → Unplanned downtime → Frequent breakdowns → Late deliveries → Unhappy customer

Key metrics include:

First pass yield	% returns	Fulfillment rate	On-time delivery	Repetitive handling
• Percent of (product made - Amount of rework)/Product Made	• Monthly quantity returned / Total quantity produced	• Number of orders fulfilled per month as a percentage	• Number of orders delivered on time per time period as a percentage	• Number of forklift trips • Number of super sacks emptied per day

Supply Chain Management - Distributor



Activities that would reduce quality are:

Improper loading → Damaged product → rework created → lost revenue

Improper packaging → Excessive handing → Lost product → Damage to product

Lack of automation → Added cost due to excessive labor → Loss of quality due to variation

Repetitive conveyance → Expense related to non-value added activities

Key metrics include:

Handling Damage

- Number of material damage incidents per period

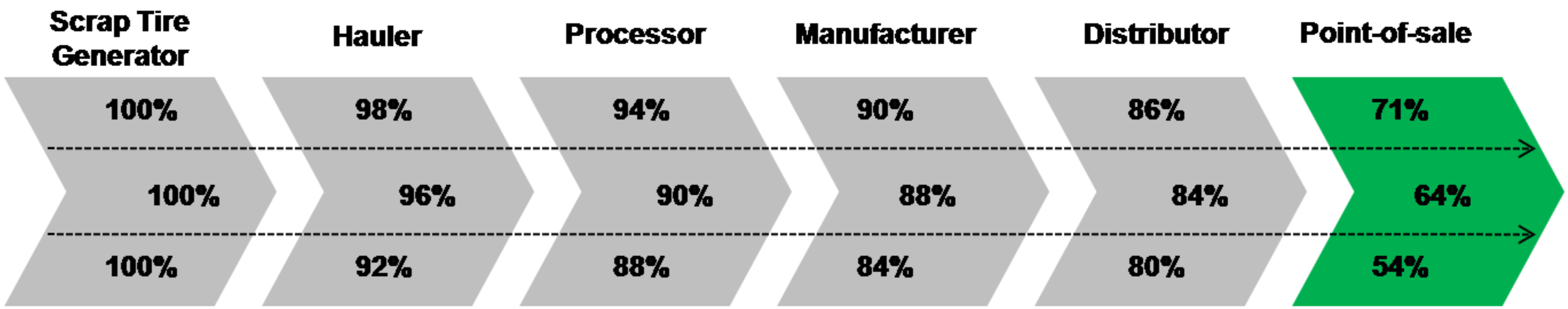
Service claims (tickets)

- Number of returns per time period
- Amount ($) of returns per time period

On-time delivery

- Number of orders delivered on time per time period as a percentage

Supply Chain Management - Point-of-Sale



Activities that would reduce quality are:

Poor quality materials → Number of returns per supplier per time period → Amount ($) of returns per supplier per time period

Mishandling → Excessive handling → Lost product → Damage to product → Sell product at a loss

Improper storage → Expense related to non-value added activities

No product-specific training → Loss of sales → Increased inventory carrying cost

Key metrics include:

Customer returns

- Number of returns per time period
- Amount ($) of returns per time period

Warranty claims

- Number of claims per time period

Loss of account or customer

- Number of accounts lost per time period (year)
- Potential revenue lost per account per time period

Lean Manufacturing

- Lean is a systematic approach to identify and eliminate waste through continuous improvement, by flowing the product at the pull of the customer in the pursuit of perfection
- Primary Goal - Eliminate Waste & Improve Efficiency
- Methodology consists of:
  - Mapping the entire value stream
  - Reducing cycle time
  - Standardizing Work
  - Continuous Improvement
- History
  - Lean Manufacturing techniques originated from Toyota Production System in the 1950's
  - The primary purpose was to optimize auto manufacturing

Goals of a Lean Manufacturing System

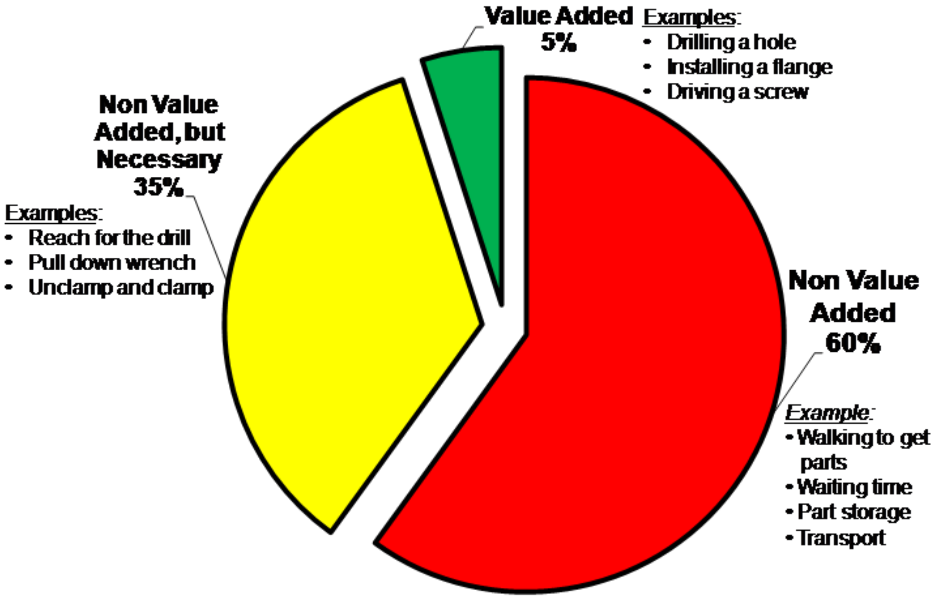
- **Improve Quality**
- **Eliminate Waste**
- **Reduce Time**
- **Reduce Total Costs**

- The steps taken to create an effective Lean Manufacturing system are:
  1. Design & develop a simple manufacturing system.
     A fundamental principle of lean manufacturing is demand-based flow manufacturing. In this type of production setting, inventory is only pulled through each production center when it is needed to meet a customer's order. The benefits of this goal include:
     - Decreased cycle time
     - Reduced inventory
     - Increased productivity
     - Increased capital equipment utilization
  2. Recognize that there is always room for improvement.

     The core of lean is founded on the concept of continuous product and process improvement and the elimination of non-value added activities. "The Value adding activities are simply only those things the customer is willing to pay for, everything else is waste, and should be eliminated, simplified, reduced, or integrated"(Rizzardo, 2003). Improving the flow of material through new ideal system layouts at the customer's required rate, would reduce waste in material movement and inventory and will improve the product quality by building quality in the process.
  3. Continuously improve the Lean Manufacturing system design.
     A continuous improvement mindset is essential to reach a company's goals. The term "continuous improvement" means incremental improvement of products, processes, or services over time, with the goal of reducing waste to improve workplace functionality, customer service, or product performance (Suzaki, 1987).
  4. Establish a measurement system (Metrics/KPI's).

     Finally, develop a set of performance metrics which is considered to fit well in a Lean environment. An example of such metric is Overall Equipment Effectiveness (OEE), which is determined by knowing the overall quality, performance and availability.

- Lean methodology is based on the concept of eliminating or reducing non-value added activities within the value stream. The non-value added activities can be systematically classified into eight categories or 8-wastes. The following chart depicts a typical value-added and non-value added distribution that exists within a value stream.



- Value added is something the customer is willing to pay for
- Value Added is anything that changes:
  - Form
  - Fit
  - Function
- Non-Value Added is: Everything else
- Non-Value Added can be further categorized as:
  - Necessary but non-value added
  - Unnecessary and non-value added

Examples of Non-Value Added Activities

Methods
- Lack of procedures
- Inconsistent training
- No specifications
- Loose or tight specifications

Customer Dissatisfaction
- Poor quality products
- Poor service
- Unsafe products

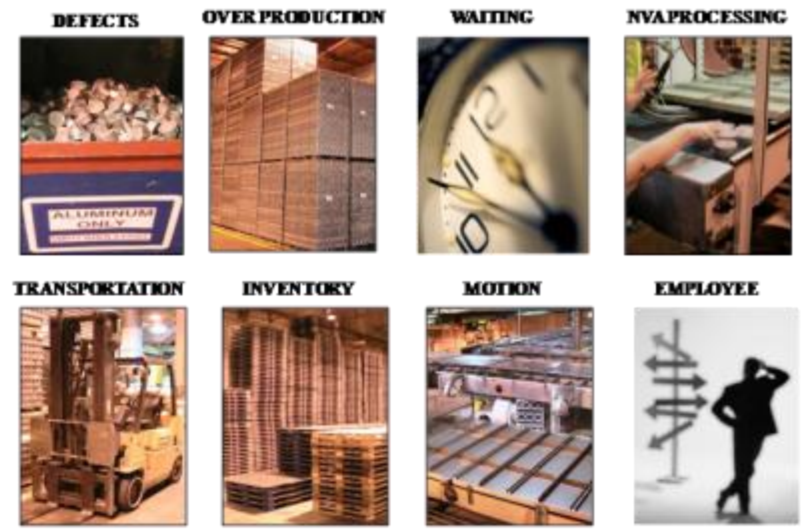
People
- Inspection
- Explaining
- Inefficient meetings
- Retraining
- Clarification

Materials
- Scrap
- Rework
- Excessive inventory
- Lost materials
- Excessive movement

Machines
- Non calibrated inspection equipment
- Non calibrated test equipment
- Non capable machines
- Idle equipment

- Classification of 8-wastes that constitute non-value added activities:

1. **Defects**
2. **Over Production**
3. **Waiting**
4. **NVA Processing**
5. **Transporting**
6. **Inventory**
7. **Motion**
8. **Employee (Underutilized People)**



Lean Manufacturing

- Lean Manufacturing principles follow a pyramid approach. The basic activity prior to all lean manufacturing deployments is implementing the 5S. The pyramid below depicts the Lean Manufacturing pyramid, which demonstrates that as an organization progresses, advanced lean manufacturing concepts are embraced and successfully deployed for further growth. It should also be noted that, as advanced practices are embraced, the basic practices should not be forgotten.

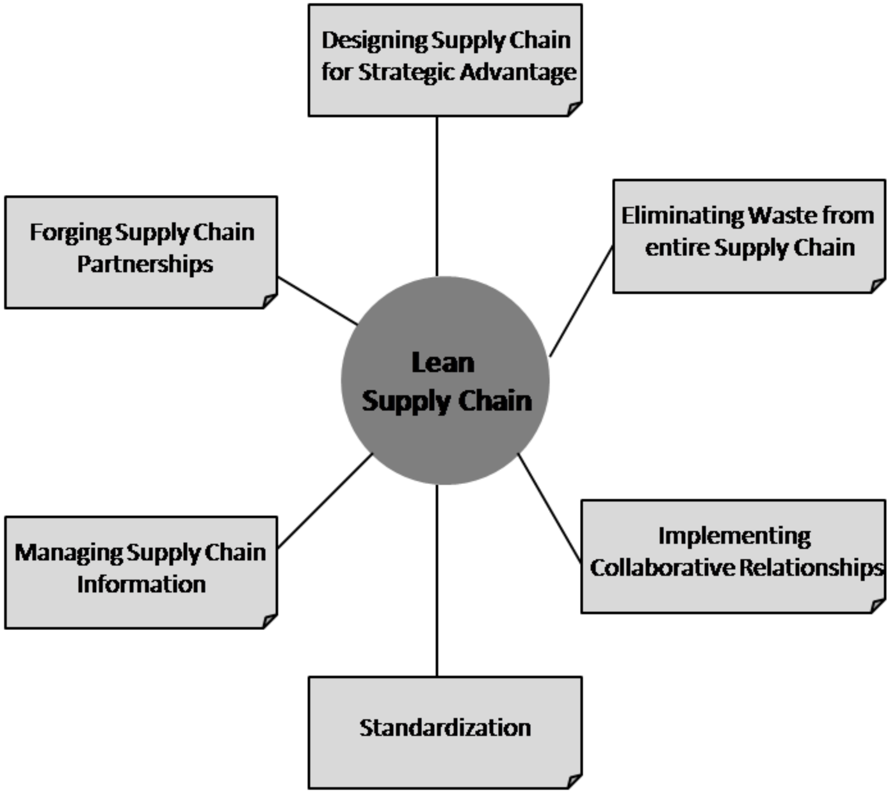
Lean Manufacturing

- The following chart depicts the importance of being Lean. This charts illustrates the extent of adoption of lean manufacturing principles and tools by the three segments within the manufacturing sector.

Tool/ Methodology	Best in Class	Average	Below Average
Education: Lean Methodology	91%	47%	16%
Identification of Improvement Opportunities	80%	43%	21%
Value Stream Mapping	70%	23%	4%
Kanban / Pull System	73%	24%	7%
Kaizen	67%	33%	13%
5S Implementation	75%	44%	19%

Lean Supply Chain

- Lean supply chain is based on TPS (Toyota Production System)
- Basic Principles include:
  - Define Product Value from Customer's point of view
  - Flow within the SC should be continuous
    - Information/Communication supporting the SC should be in parallel with the above Flow
  - Entire Value chain needs to continue to move towards perfection, concentrating on the elimination of waste and the addition of value in all of its supply chain processes
- Necessary Attributes
  - Demand Management, Process and Product Standardization, Industry Standardization, Collaboration, Cultural Change.

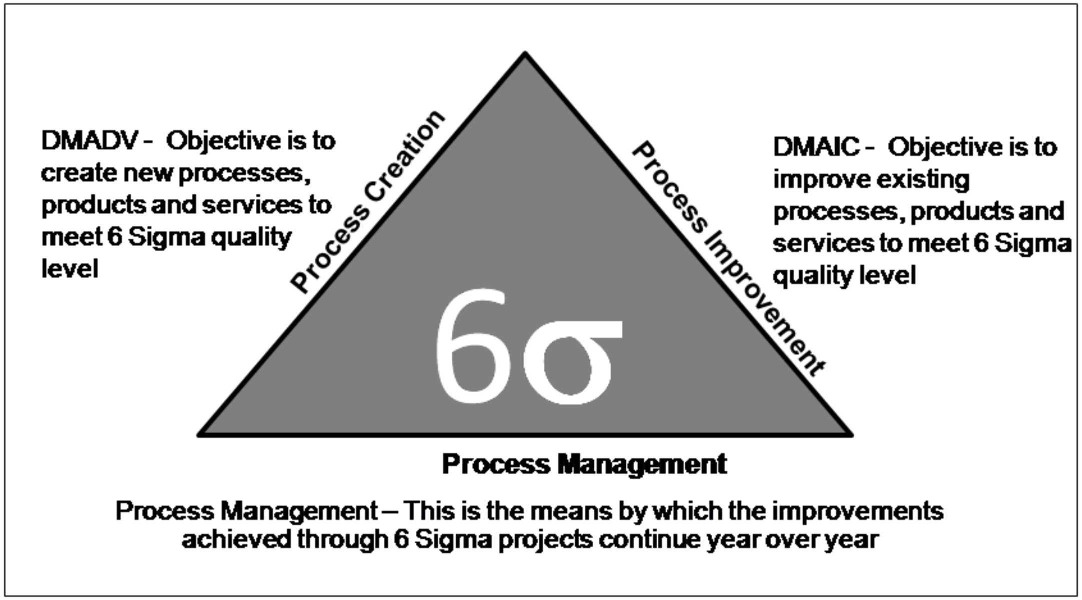


Six Sigma

What?
Six Sigma is a fact-based, data-driven philosophy of improvement that values defect prevention over defect detection.

6 Sigma is an adept methodology to minimize or **eliminate variance, ensuring the output meets quality** requirements each time and every time.

Six Sigma is a measure of variability. Six Sigma is a name given to indicate how much of the data falls within the customers' requirements. The higher the process sigma, the more of the process outputs, products and services, meet customers' requirements – or the fewer the defects.

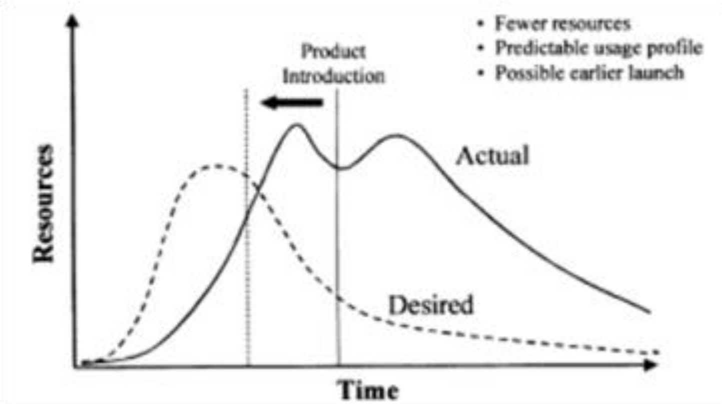


The core concepts around which six sigma revolves are:

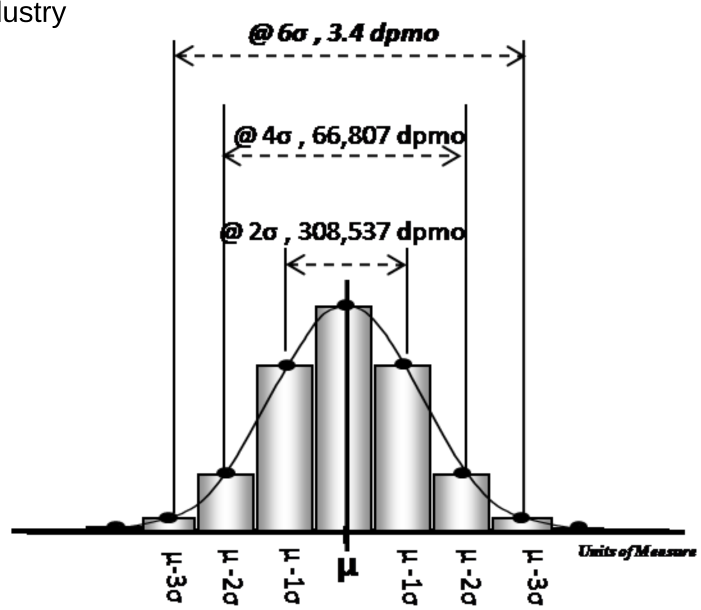
- **Critical to Quality:** Attributes most important to the customer
- **Defect:** Failing to deliver what the customer wants
- **Process Capability:** What your process can deliver
- **Variation:** What the customer sees and feels
- **Stable Operations:** Ensuring consistent, predictable processes to improve what the customer sees and feels
- **Design for Six Sigma (DFSS):** Designing to meet customer needs and process capability

Six Sigma

- Goal - Eliminate Variation & Improve Accuracy
- Methodology Consists of:
  - Approach (DMAIC or DMADV)
  - Reduction in variation
  - Project management
  - Data driven analysis/ statistics
  - Breakthrough improvement
- History
  - Originated at Motorola (1980's)
  - Purpose was to reduce variation in semiconductor industry



Source: Benefits, obstacles, and future of six sigma approach, Young Hoon Kwak and Frank T. Anbari

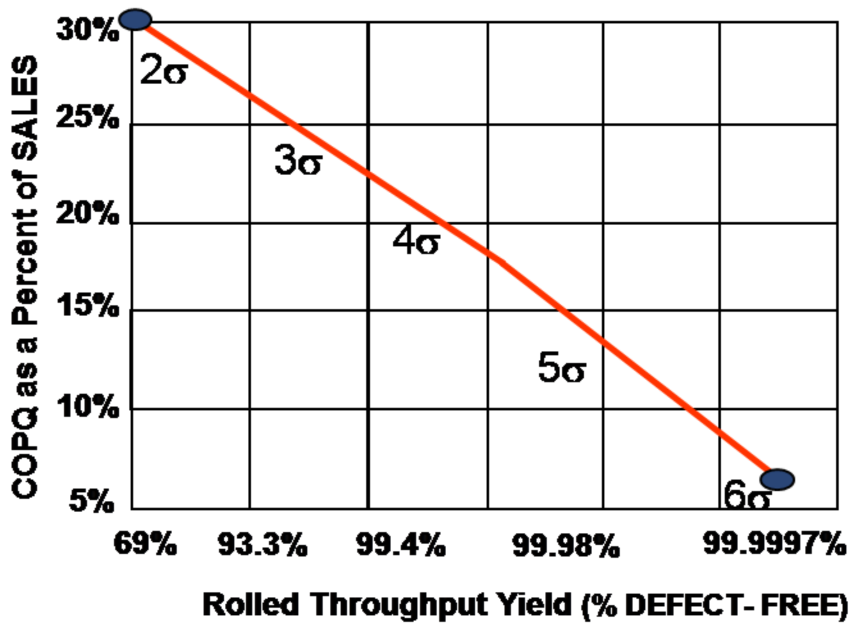


Six Sigma

- Performance at various sigma levels
  - With performance at 2 Sigma:
    - 69.146% of products and/or services meet customer requirements with 308,538 defects per million opportunities
  - With performance at 4 Sigma:
    - 99.379% of products and/or services meet customer requirements … but there are still 6,210 defects per million opportunities
  - With performance at 6 Sigma:
    - 99.99966% - As close to flawless as a business can get, with just 3.4 failures per million opportunities (e.g., products, services, or transactions)

Type	At 4σ Level	At 6σ Level
Postal Delivery in US	20,000 lost mails per hour	7 lost mails per hour
Surgical Operations in US	5,000 incorrect surgical operations per week	1.7 incorrect surgical operations per week
Flight Landings in US	Two short or long landings at most major airports daily	One short or long landing at major airports each year
Drug Prescriptions in US	200,000 incorrect drug prescriptions each year	68 incorrect drug prescriptions each year

Cost of poor quality (COPQ) at various sigma levels

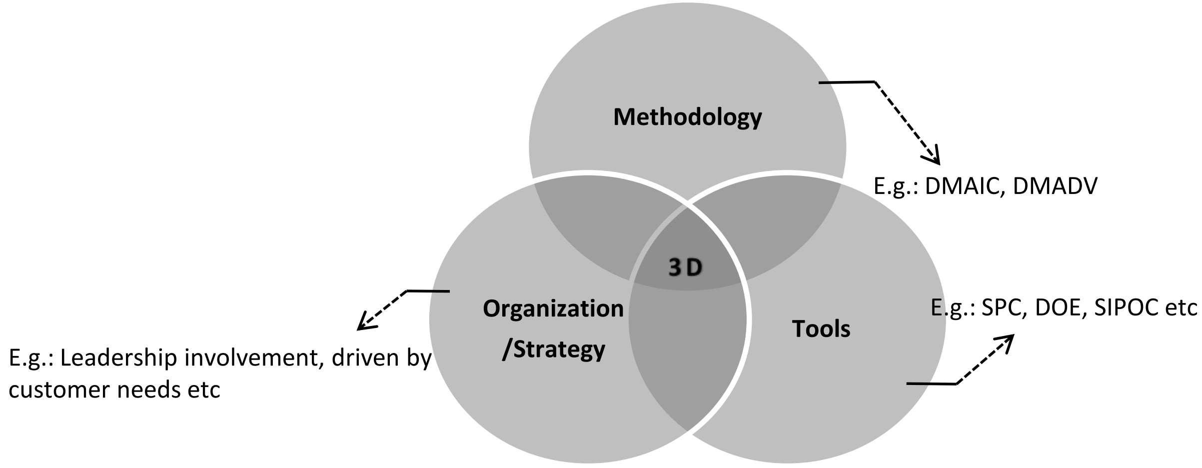


** Source: Caterpillar Inc*

Note: Motorola noted that many operations, such as complex assemblies, tended to shift 1.5 sigma over time. So a process, with normal distribution and normal variation of the mean, would need to have specification limits of ± 6 sigma in order to produce less than 3.4 defects per million opportunities. (Source: Six Sigma QCI Primer)

Six Sigma

- Approach to Six Sigma
  - The comprehensive approach addresses all three dimensions important to the success of Six Sigma initiative in your organization.
    - Dimension 1: Organizational and Strategy: This step involves developing strategic business goals by relentlessly aligning market and customer needs with that of the enterprise.
    - Dimension 2: Methodology: Based on the business goals and needs, in this step, proven high impact methodologies such as: DMAIC (Define – Measure – Analyze – Improve – Control/Close) DMADV (Define – Measure – Analyze – Design – Verify/Validate), etc. are implemented.
    - Dimension 3: Tools: This step involves deployment of powerful, reliable, and easy-to-use tools to analyze your data and improve your processes. Some of these include: Process maps, DOE, SPC, Impact-Effort chart, ANOVA etc.



Sample Six Sigma Tool Box

Define	Measure	Analyze	Improve	Control
Benchmarking	Value Stream Map	Fishbone Diagrams	Modeling	SPC Charts
Process Flow Mapping	Cause & Effect	FMEA	Tolerance Control	Performance Metrics
Flow charts	Defect Metrics	Root Cause Analysis	Defect Control	Multiple Regression
Project Charter as a Team	Statistical Analysis	ANOVA	Design Changes	Train
Set Up a Plan & Guidelines for Team	Data Collection Run Charts, Time Series Charts, Time Value Charts, Pareto Charts	Cause & Effect Diagram	Piloting	
Review Existing Data	Sampling	Scatter Plots	Best Practices	
SIPOC				

Key Roles in Six sigma Deployment

Executive Leadership includes CEO and other key top management team members. They are responsible for setting up a vision for Six Sigma implementation. They also empower the other role holders with the freedom and resources to explore new ideas for breakthrough improvements.

Champions are responsible for the Six Sigma implementation across the organization in an integrated manner. The Executive Leadership draws them from the upper management. Champions also act as mentors to Black Belts.

Black Belts operate under Master Black Belts to apply Six Sigma methodology to specific projects. They devote 100% of their time to Six Sigma. They primarily focus on Six Sigma project execution, whereas Champions and Master Black Belts focus on identifying projects/functions for Six Sigma.

Green Belts are the employees who take up Six Sigma implementation along with their other job responsibilities. They operate under the guidance of Black Belts and support them in achieving the overall results.

Six Sigma

Six Sigma Results

- Creates competitive advantage
- Enhances revenues
- Accelerates overall business growth
- Develops new business opportunities
- Lowers costs incurred due to:
  - Scrap ~ 80% reduction
  - Rework ~ 75% reduction
  - Defects ~ 70% reduction
- Improves:
  - Productivity ~ 70% improvement
  - Process Yield ~ 80% improvement
  - Cost Savings ~ 60% improvement

Company	Savings (in millions)	Timeline (in months)
Caterpillar	$500	24
Bank of America	$2000	72
StorageTek (one division)	$0.40	3
GE	$2700	24
US Army	$2000	72
CIGNA	$200	12
POSCO	$1000	60
Scottish Power	$170	36
Anonymous Client 1 (Annual Revenue = $20 M)	$0.85	6
Anonymous Client 2 (Annual Revenue = $30 M)	$2.0	14
Anonymous Client 3 (Annual Revenue = $455 M)	$2.5	11

Total Quality Management (TQM)

- **Total quality management** (**TQM**) is a management philosophy that seeks to integrate all organizational functions (marketing, finance, design, engineering, and production, customer service, etc.) to focus on meeting customer needs and organizational objectives. TQM empowers the Total organization, from the employee to the CEO, with the responsibility of ensuring Quality in their respective products and services, and Management of their processes through the appropriate process improvement channels. All types of organizations have deployed TQM, from small businesses to government agencies like NASA , from schools to construction firms, from manufacturing centers to call centers, and from dance schools to hospitals. TQM is not specific to one type of enterprise, it is a philosophy applied anywhere quality is required.

Total quality management (TQM)

Customer Focus

- Supplier partnership
- Service relationship with internal customers
- Never compromise quality
- Customer driven standards

Supplier Development & Involvement

- Plan (drive, direct)
- Do (deploy, support, participate)
- Check (review)
- Act (recognize, communicate, revise)

Fact Based Decision Making

- SPC (statistical process control)
- DOE, FMEA
- The 7 statistical tools
- TOPS (8D - Team Oriented Problem Solving)

Employee Empowerment

- Training
- Suggestion scheme
- Measurement and recognition
- Excellence teams

Continuous Improvement

- Systematic measurement and focus on CONQ
- Excellence teams
- Cross-functional process management
- Attain, maintain, improve standards

Total Quality Management (TQM)

- TQM focuses on the process by which work gets done. The person most familiar with that process is the individual worker responsible for making it work. Often, a process is either unmanageable or just plain unworkable. In a rigid bureaucracy, for workers to persuade upper echelons of the need to change a procedure is nearly impossible. Under TQM, management is responsible for making a particular job as easy as possible for workers. Supervisors and managers monitor the work process and respond to suggestions from the work force concerning unworkable procedures. Sailors in particular are infamous for coming up with nonstandard (but workable) solutions to problems. In some cases, this results in unsafe practices. However, these solutions are often extremely practical. We must develop the ability to ferret out these improvements and incorporate them into standard procedures that serves a dual purpose. First, it ensures the recommended improvement is usable and meets all applicable standards. Second, the improved method is made available to everyone involved in that process. Both of these purposes serve a practical application of "working smarter, not harder".

- TQM encourages "More bang for the buck"
- How doesTQM directly affect product or service Quality?
  - A popular myth holds that increased quality results in increased costs and decreased productivity. In reality, improved quality ultimately results in decreased costs and increased productivity. How can this be true? Using the TQM approach, focus on quality extends the time between failures on equipment and improves the efficiency of our operations. It reduces rework requirements as well as the need for special waivers of standards. It also reduces mistakes and produces monetary savings through more efficient use of scarce resources.
- Benefits:
  - Increased pride of workmanship among individual workers
  - Increased readiness
  - Improved sustainability caused by extended time between equipment failures
  - Better justification for budgets because of more efficient operations
  - Streamlined maintenance and production processes

VIII. Case Studies

- Real life case studies specific to the manufacturing industry and to the rubber recycling industry are discussed in this section. The case studies focus on the efficacy of QA/QC tools and techniques. The six case studies discussed in this section encompass the following sectors:
  - Construction (1 case study)
  - Defense (1 case study)
  - Food and Beverage (1 case study)
  - Rubber recycling (3 case studies)

Reduced defect rate by more than 50% using effective Quality Assurance Program

Problem Statement: Builders wanted to improve the quality of work available in the marketplace. Errors and defects were frequent, and the need for practical and effective methods to improve one of the most critical construction essentials–trade contractor quality was identified.

Solution: This project was a combined effort of HUD and the NAHB Research Center. The following steps were followed by the contractors to implement a Quality Assurance program:

<u>Step 1</u>: A seminar provided an overview of how the quality system works. Participants previewed the implementation process and developed a project plan. The company president named a quality representative.

<u>Step 2</u>: A baseline assessment analyzed quality performance and current quality assurance practices. Each contractor developed a customized quality manual that built on its quality accomplishments. The manuals contain policies, procedures, and forms specific to customer requirements, construction methods, division of labor, and organizational structure.

<u>Step 3</u>: Each contractor prepared an approved material list of commonly used building products, required equipment and workmanship tolerances. These items, along with related installation instructions, were added to the quality manual. Foremen and superintendents were formally evaluated and qualified to lead and/or inspect specific types of work crews. At the end of this step, the contractor introduced the quality system to employees.

<u>Step 4</u>: Inspection forms were tailored to the company's existing field reporting requirements. A single form tracked production status as well as quality data. Field employees were trained in the new inspection procedures, which then took effect.

<u>Step 5</u>: Managers and superintendents began documenting their field review observations. Contractors institutionalized regular training of field employees on quality hotspot improvements. Contractors initiated the administrative procedures for managing the quality system.

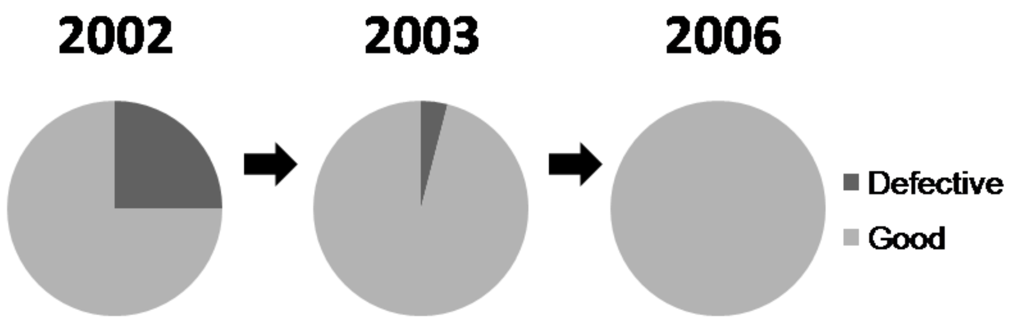
<u>Step 6</u>: Monitoring of the system operation led to adjustments and refinements. Contractors tracked the benefits of the quality system for comparisons with the baseline data identified in step two. After six months of operation, audits verified system operation.

Result: First-year results include defect rates reduced by more than 50 percent, productivity improvements offset regional labor rate increases of over 7 percent, and builder satisfaction improved to top ratings.

Reduced defect rate by more than 84% in one year, improving profitability

Problem Statement: Workers at a U.S. Navy ship-repair facility in Japan were encountering too many costly defects when using a "powder coat" process to paint ship parts.

Solution: SRF-JRMC Sasebo used the following methodology:



Step 1: Brainstormed to assess the situation and identify challenges.

The challenges identified were:

- New process
- No experience
- No instruction
- No specialized knowledge
- No technical work documents
- No external support
- Low cost awareness

Step 2: The team began a kaizen activity by:

- Setting goals
- Identifying stakeholders
- Brainstorming root causes

Step 3: The team used direct observation and brainstorming to determine the cause of defects in multiple-color powder- coat jobs.

Step 4: The team then conducted a time study and cost analysis to quantify the impact of these defects.

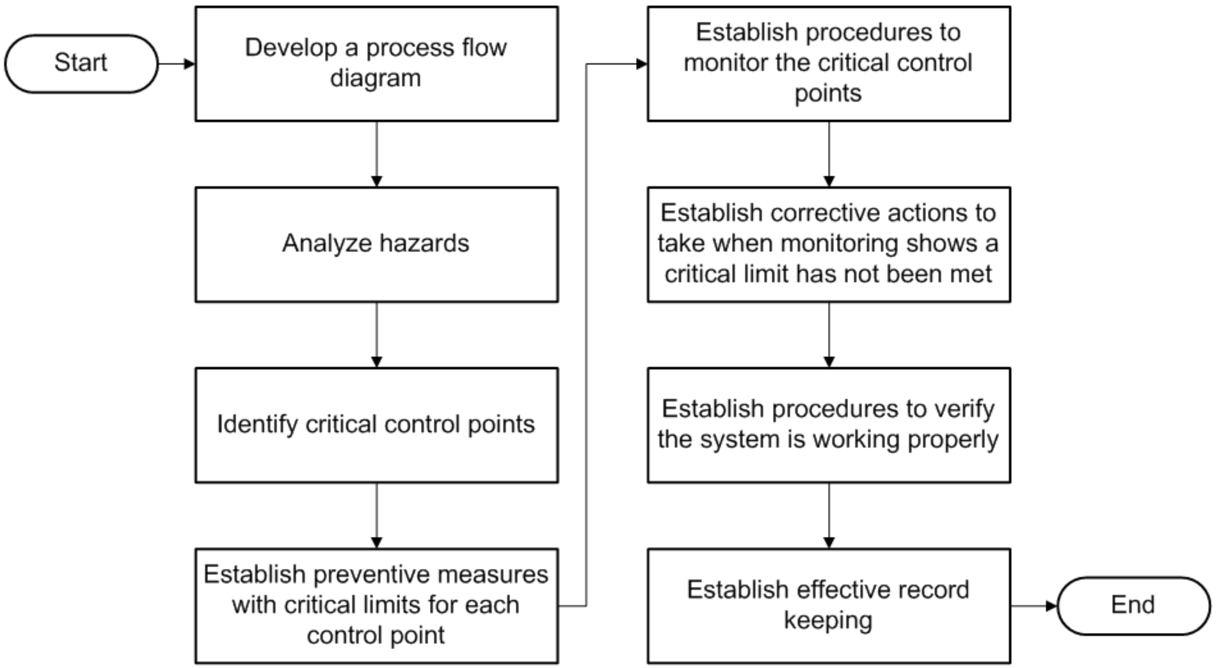
Step 5: The team ran experiments and methodical tests to determine the best solution.

Result: In cost savings, the elimination of defects has saved the facility $120,000. In cost avoidance, it's saved a whopping $480,000 since 2002. Powder-coating jobs at SRF-JRMC Sasebo increased from about 1,500 in 2002 to more than 3,300 in 2005.

Ensure food safety from farmland to consumers, using HACCP Quality Control

Problem Statement: Rising food safety incidents

Solution: According to the FDA, the HACCP system requires seafood companies to follow an eight step quality control methodology.



Result: HACCP is one of the most important quality control tools in food safety, having proven its effectiveness since its implementation in 1998, according to the USDA announcement.

Effective QA/QC practices lead to a dramatic turnaround for a large playground rubber manufacturer

Problem Statement: A large playground rubber supplier lost a lucrative contract for a major city suburb. Studies revealed that lack of QA /QC practices led to steel and fiber contamination of playground rubber supplied by this manufacturer. This rubber was used in several playgrounds in one city. Several cases of breathlessness due to fiber inhalation, rashes and bruises caused by steel fragments, and skin irritation caused by low-grade dye/color were reported.

Solution: The supplier of playground rubber, that also happens to be the manufacturer/processor of the recycled rubber, conducted a complete review of the deficiencies that led to the loss of such a lucrative contract and that caused worrisome safety issues after installation.

Step 1: Diagnosis – A thorough review revealed that the rubber recycler lacked an effective QC/QC practice within its enterprise. The review also revealed that the personnel responsible for final product inspection, if at all conducted, were not trained properly to judge the quality of the final product.

Step 2: A problem solving exercise was conducted with an intent to determine the root cause and the subsequent corrective action to the existing problem. A secondary intent of this exercise was to adopt a proactive approach by determining the preventive actions to avoid any similar potential problems in the future.

Step 3: The problem solving exercise identified action items based on the gap analysis performed. One of the foremost action items identified was development of an effective QA/QC program, incorporating the best-in-class manufacturing practices. Another action item was training the employees and identifying potential “trainers” among the employees for future training programs.

Step 4: The next step was development of a QC plan and tools that were recommended to be used to control quality at various levels in the process stream. Metrics were also established and tracked to monitor progress. Moreover, best-in-class practices were also adopted by this rubber recycler to stay ahead in the industry and to ensure that they were the early adopters of any new technology or processes. The recommended standards & specifications and regulatory compliances were meticulously adopted.

Result: In the course of several months, the first-pass yield of the rubber recycler improved from a poor 55% to 85%. Internal rework decreased by over 70% and customer complaints reduced by 90%. The company, due to its high volume production and significantly improved quality was able to win new lucrative bids.

Adoption of standard QA/QC practices lead to significant annual savings and significant business growth for a TDA supplier

Problem Statement: The cost of road maintenance was a significant burden on a local government's budget. Regular repairs, costly alternatives, long lead times, frequent & forced maintenance and potential safety hazards due to damaged roads was costing a city council about 20% of its annual expenditure. The council tried several alternatives in the past, including a few recycled rubber options, but the disappointment was only delayed.

Solution: The city council conducted an inquiry at the request of one of its team members and identified that tire derived aggregate (TDA) manufactured under tight QA/QC practice could be the long-term answer to its current issues. This will not only significantly increase the longevity of the roads, but also yield substantial savings in the long run.

Step 1: Conducted gap analysis between the existing materials and the one considered. Identified pros and cons for each alternative and deduced the benefits and annual savings of using TDA over existing materials.

Step 2: Obtained TDA produced under strict QA/QC practices to reseal the damaged roads. Where degradation was more intense, through accelerated wear or water cracking the pavement surface, additives such as recycled rubber were included in the bitumen mix. The rubber gave the seal elasticity allowing pavement flexibility where cracks can develop.

Step 3: Conducted tests to ensure that the TDA can be mixed onsite, unlike other alternatives, with the bitumen.

Step 4: Tested the prototype installation using industry standards and specifications, ensuring regulatory compliance and safety concerns were addressed.

Step 5: Once the tests were positive, the TDA reseal was installed across several stretches.

When comparing maintenance options in the table on the right, it is clear that the use of recycled rubber as a component of the resealing mix is more cost effective.

Maintenance Option	$/m^2	Comparative Cost
Recycled rubber & bitumen mix	2.5	$200,000
Polymer modified & bitumen mix	2.7	$216,000
Reconstructing surface	20	$1,600,000

Result: $1.4 million in annual savings by maintaining the road surface through the application of recycled rubber seal. $16,000 in annual savings by using recycled rubber sealer instead of the polymer modified alternative on degraded road surfaces. Recycling of 1,600 tires annually through Council's use of the recycled rubber product, diverting 16 tons of material into a more productive use.

Root Cause Analysis and QA/QC at critical control points lead to significant reduction in rejects and warranty returns

Problem Statement: A manufacturer of sidewalks made out of recycled rubber was experiencing abysmal first-pass-yield (below 50%) and high volume of warranty related returns. The problem – cracking of its sidewalks and eventually splitting apart with months of installation. This not only shot the cost incurred due to rework and warranty, but also negatively affected the goodwill of the company, leading to decrease in sales.

Solution: The manufacturer, with some external assistance, conducted a root cause analysis of the existing problem , using basic fishbone chart and 5WHY analysis. After this analysis, it occurred to them that the QA/QC checks were missing from critical areas. Moreover, it was also revealed that the binding agent used during manufacturing was of inferior quality.

Step 1: Problem Analysis and Brainstorming: The internal team, with some external assistance, carefully defined the problem and performed brainstorming to come up with potential issues that might be causing the existing problem.

Step 2: Identifying the root cause: Using the list of potential issues, the team went over all the issues and narrowed down to the significant few. After this, using their past experience, the team conducted few physical analyses and identified the binding agent as a potential root cause. The team also noted that lack of QA/QC at critical points led the problem to slip through, eventually passing it on to the customer.

Step 3: Identifying and implementing the solution: The team decided to notify the current supplier of the binding agent, making the supplier aware of new metrics that the supplier will be measured against and giving the supplier a chance to improve its product quality. The team also identified critical points (mostly in the upstream processes) where QA/QC will be put in place, to avoid passing on defects to downstream processes.

Step 4: Measuring the results: In the next few months, the team noted that with the new controls in place and with use of a good quality binding agent (through same supplier), the number of rejects dropped significantly and the warranty returns almost became negligible. This confirmed that the team had identified the correct root cause to its problem and ensured that quality was built into the process, yielding an acceptable quality product.

Result: Once the new system was in place, parameters such as first-pass-yield, defect rate and warranty returns were consistently measured for few months. The first-pass-yield shot up to 87%, the internal defect rate dropped by more than 75% and the warranty returns dropped by over 98%. The manufacturer also saw an uptick in its sales in form of repeat business and new business from various counties.

IX. Appendix

Five Steps to Better Quality

1. Leadership commitment
2. Develop company-wide improvement council
3. Develop quality improvement teams
4. Become a learning organization
5. Supplier involvement and supplier development

Five Steps to Better Quality

1. Leadership Commitment: Quality starts with senior leadership
   - Issue a quality policy
     - The quality policy sets the general direction of the organization.
   - Conduct employee surveys
     - These surveys must be conducted periodically to measure the pulse of the organization.
     - The individual survey must be kept confidential to retain its usability.
   - Performance Standard
     - To begin its journey of continuous quality improvement, an organization must have performance standards.

2. Develop Company-wide Quality Council: A cross-function team of people to lead the initiative
   - Become a learning organization
     - Teach everyone in the organization about the quality objectives and standards.
   - Define quality objectives for the organization as a whole
     - This encompasses what improvement methods to employ, who is responsible, and what measurement will be used.
   - Develop and help implement the company improvement strategy
     - Roadblocks and system problems must be resolved to gain quality improvements.
   - Report quality cost
     - There is no better way to encourage quality improvement, than to show that good quality saves money and that poor quality costs a great deal.
   - Develop and maintain an awareness program
     - Continuous emphasis on excellence, sharing of success stories, recognition and setting new standards are part of this process.

Five Steps to Better Quality

3. Establish Quality Circles: A team of people focused on a quality concern
    - Train and educate the teams on:
        - Process improvement methodologies
        - Practical problem solving
        - Data collection and analysis
    - Data collection
        - To track problem occurrences, certain tools such as checklists and tick sheets should be used.
    - Problem solving and decision making
        - Each time the root cause of a problem is found and the issue is resolved, it should be documented and the subsequent gains captured for future decision making purposes.

4. Become a Learning Organization
    - Involve every person in continuous improvement activities and make each person aware of his or her roles and responsibilities/contribution towards the overall quality of the product or service that the organization provides its customers.
    - A successful organization motivates its employees at every level and gets the most out of their investment.
    - A company that treats its employees well and shows a sincere desire in individual development, stands the best chance of benefitting the most from employee involvement.
    - Quality cannot be just achieved without the consistent effort of each individual in the organization.

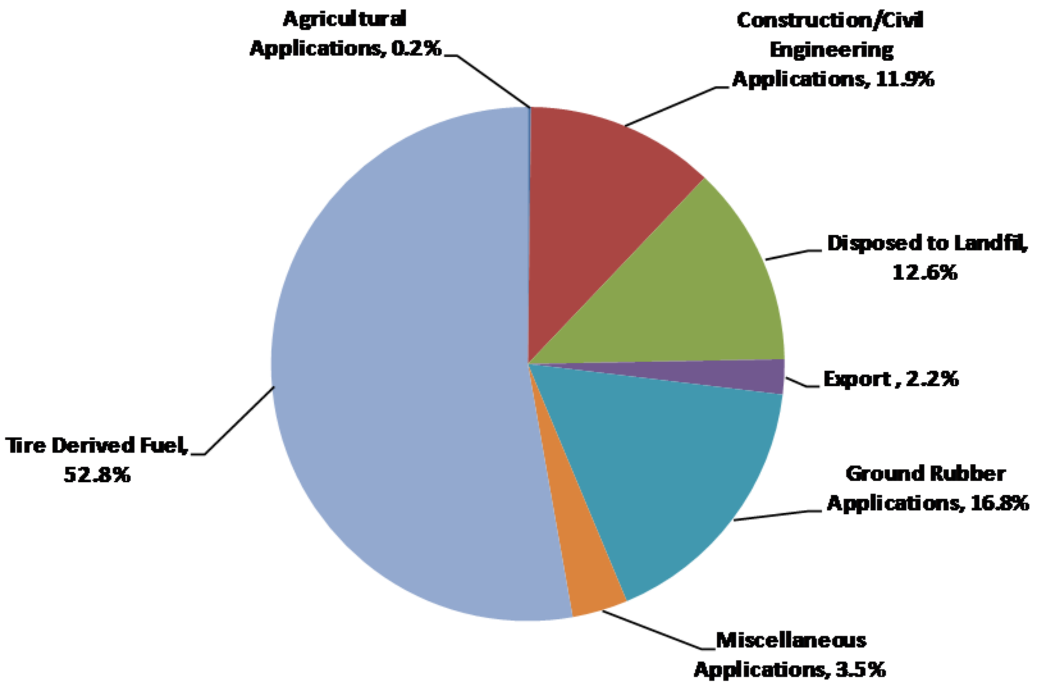
Quality is everyone's business. – Dr. Deming

5. Supplier Involvement and Supplier Development
    - The quality of the finished product is also determined by the quality of the materials used. Therefore, the supplier of these raw materials plays a critical role in defining the overall quality of the product.
    - Developing the supplier’s capability to produce high quality products will help strengthen the supplier relationship.
    - Maintaining long term contracts with the suppliers increases the probability of greater supplier reliability.

Issues due to lack of QA/QC for Various Product Categories

We have categorized the post-recycling applications of scrap tire into six categories:

- Tire Derived Fuel
- Ground Rubber Applications
- Construction/Civil Engineering Applications
- Agricultural Applications
- Miscellaneous Applications
- Export



Scrap Tire Disposition Trend in US (2007)
(Source: Scrap Tire Markets In The US, May 2009, RMA

Issues due to lack of QA/QC for Various Product Categories

Category: Ground Rubber Applications

Primary Issues:

- Potential health issues and chemical exposure in recreational applications
- Failure to comply with ADA (American Disabilities Act) requirements
- Potential exposure to lead
- Poor installation may cause safety and product life issues
- Risk of having elevated temperatures (surface heating) during summer
- Presence of steel and fiber
- Appearance of skin sensitization or eliciting a reaction from already sensitized individuals
- Failure to comply with HIC (Head Impact Criteria) requirements

Reasons for Issues:

- Poor (or lack of) adherence to standard QA/QC practices
- Inherent product properties
- Lack of uniform standards and specifications
- Poor manufacturing process
- In some cases, poor machines

Issues due to lack of QA/QC for Various Product Categories

Category: Tire Derived Fuel

Primary Issues:
- Release of toxic gases

Reasons for Issues:
- Uncontrolled burning in poorly designed kilns

Issues due to lack of QA/QC for Various Product Categories

Category: Civil Engineering/Construction Applications

Primary Issues:
- Settlement of recycled rubber leading to separation from asphalt
- Drop in effectiveness of RAC during cold weather
- Poor performance of baled tire applications

Reasons for Issues:
- Difference in specific gravity of ground rubber (1.15) compared to asphalt (1.00)

Issues due to lack of QA/QC for Various Product Categories

Category: Disposed to Landfills

Primary Issues:

- Tires do not significantly decompose when buried and have a tendency to rise to the surface, compromising the suitability of the landfill sites for future development
- Tires improperly disposed of, either in landfills or left on the surface of the ground, provide excellent breeding grounds for diseases carrying microbes and pests
- Huge tire stockpiles have proven to be a threat to public safety and environmental quality
- The occasional fires that arise in such tire stockpiles are costly and difficult to control
- Failure of Leachate collection systems

Reasons for Issues:

- Non-compliance to regulations
- Poor QA/QC procedures at landfill sites
- Lack of awareness
- Poorly designed Leachate collection systems

Cost of Quality – Metrics

- **Detailed Metrics**
  - cost of assets and materials
  - cost of preventive labor
  - cost of appraisal labor
  - cost of defects per 100 pieces
  - cost of late deliveries
  - percentage of repeat sales
  - time between service calls
  - number of non-conforming calls
  - number of complaints received

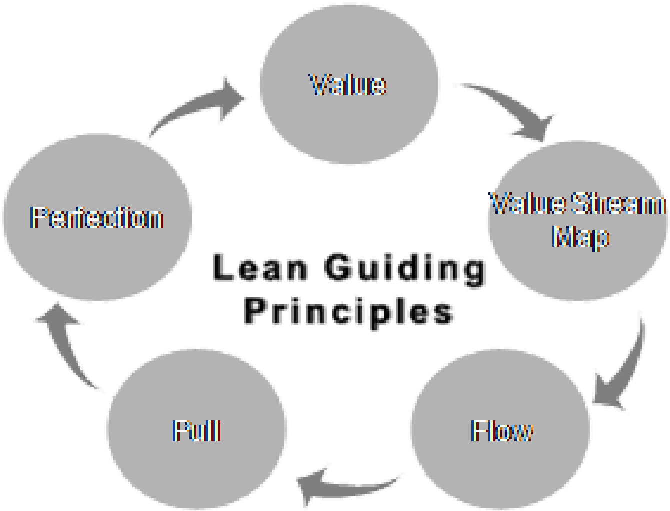
- **Global Metrics**
  - Return on Quality(RoQ) = Increase in Profit/Cost of quality improvement program
  - Quality rate ={input – (quality defects + startup defects + rework)}/input
  - Process quality = {available time – rework time}/ available time
  - First time quality (% product with no rework)

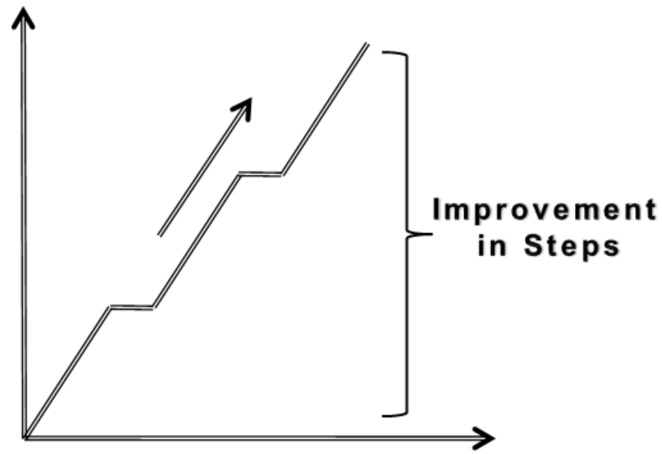
Examples of Successful Implementation of PAF Model

Company	*Industry*	*CoQ calculation*	*Base for CoQ calculation*	*Reported gains*	*Reference*
P-A-F model					
United Technologies/ Essex Group, USA	telecommunications	**CoQ = P+A+F**	% of total manufacturing cost % of cost of goods produced	• CoQ reduced from **23.3% to 17.2%** in 5 years. • gain in productivity of 26%	Fruin, 1986
AT&T Bell Laboratories	telecommunications	**CoQ = P+A+IF+EF**	% of project budget		Thompson and Nakamura, 1987
Hydro Coatings, UK	industrial coatings manufacturing	**CoQ = P+A+IF+EF**	% of annual sales turnover % of raw material usage	• CoQ reduced from **4.1% to 2.5%** in 4 years. • investment in quality paid back in the first year.	Purgslove and Dale, 1995; Purgslove and Dale, 1996
Philips Power Semiconductor Business Group, UK	electronics	**CoQ = P + A + CONC**	% of factory turnover	• CoQ reduced from **35.8% to 18.1%** in 4 years • workforce reduced by 25% in 18 months • output increased by 25% in 18 months	Payne, 1992
York International, UK	air conditioning and refrigeration	**CoQ = P+A+IF+EF**	% to cost of sales	• CoQ reduced from **13.5% to 3.7%** in 8 years • the cost of factory failures reduced by 96%	Knock, 1992
British Aerospace Dynamics, UK	aerospace	**CoQ = P+A+F**	% of total manufacturing cost	• objective to reduce CoQ by one third in one year	Hesford and Dale, 1991
ITT Europe, Belgium	information technology	**CoQ = P+A+F**	% of sales	• Savings from CoQ improvement program totaled over $ 150 million in 5 years	Groocock, 1980
Allis-Chalmers Corporation, US	machinery manufacturing	**CoQ = P+A+IF+EF**	% of product sales	• CoQ reduced from **4.5% to 1.5%** in 3 years	Kohl, 1976

Lean Manufacturing

- Lean is a systematic approach, to identify and eliminate waste through continuous improvement by flowing the product at the pull of the customer in the pursuit of perfection
- Goal - Eliminate Waste & Improve Efficiency
- Methodology consists of:
  - Mapping the entire value stream
  - Reducing cycle time
  - Standardizing Work
  - Continuous Improvement
- History
  - Based on the Toyota Production System
  - Purpose was to optimize auto manufacturing





Continuous Improvement Philosophy

Glossary to Terms (1 of 3)

- **5WHY** - is a method to pursue the deeper, systematic causes of a problem and eventually allows you to develop a corresponding countermeasure. This is a problem solving tool that leads employees to the root cause of a problem, by asking "WHY" 5 times.
- **Ambient Grinding** – The ambient process often uses a conventional high powered rubber mill set at a close nip, and the vulcanized rubber is seared and ground into a small particle.
- **American National Standards Institute (ANSI)** - US non-government organization which develops and publishes standards for almost the entire US industry. Its standards setting procedure provides a forum for discussion among academics, special interest groups, users, and vendors. An ANSI standard, though termed 'voluntary,' carries a lot of clout in the US and elsewhere.
- **Best-in-Class** - Highest current performance level in an industry, used as a standard or benchmark to be equaled or exceeded.
- **Cause-Effect diagram** - is one of the most effective tools used during problem solving. This tool is used to identify potential causes of an issue/problem. The issues can be grouped into six categories – Man, Machine, Method, Material, Maintenance and Environment.
- **Cost of Quality (CoQ)** - is usually understood as the sum of conformance plus nonconformance costs, where cost of conformance is the price paid for *prevention* of poor quality (for example, inspection and quality appraisal) and cost of non-conformance is the *cost* of poor quality caused by product and service failure (for example, rework and returns).
- **Cryogenic Grinding** – Cryogenic grinding usually starts with chips or a fine crumb. This is cooled using a chiller. The rubber, while frozen, is put through a mill. This is often a paddle type mill.
- **DPMO** – DPMO stands for defects per million opportunities. DPMO is a metric that captures nonconformities per million opportunities. DPMO comprehends the possibility that a unit under inspection may be found to have multiple defects of the same type or may have multiple types of defects.
- **Hazard analysis and critical control point (HACCP)** - Hazard analysis and critical control point. Food production, storage, and distribution monitoring system for identification and control of associated health hazards. It is aimed at prevention of contamination, instead of end-product evaluation.

Glossary to Terms (2 of 3)

- **Institute of Electrical and Electronics Engineers (IEEE)** – IEEE is an international nonprofit, professional organization for the advancement of technology related to electricity.
- **Impact-Effort Chart** - The Impact-Effort chart is used to prioritize the order in which the issues should be addressed or the order in which the corrective actions should be implemented. The y-axis (Impact) relates to the impact that resolution to a particular issue might have. The x-axis represents the effort needed to implement the resolution.
- **International Playground Equipment Manufacturers Association (IPEMA)** - provides 3rd party Product Certification services for U.S. and Canadian public play equipment and public play surfacing materials in the U.S. IPEMA service IPEMA-certified member companies, affiliated playground industry groups and anyone with an interest in playground equipment regulations.
- **International Standards Organization (ISO)** - Popular name for International Organization For Standardization (IOS), a voluntary, non-treaty federation of standards setting bodies of some 130 countries. Founded in 1946-47 in Geneva as a UN agency, it promotes development of standardization and related activities to facilitate international trade in goods and services, and cooperation on economic, intellectual, scientific, and technological aspects.
- **Key Performance Indicators (KPI)** - Key business statistics such as number of new orders, cash collection efficiency, and return on investment (ROI), which measure a firm's performance in critical areas. KPIs show the progress (or lack of it) toward realizing the firm's objectives or strategic plans by monitoring activities which (if not properly performed) would likely cause severe losses or outright failure.
- **Laggard** - In the diffusion of innovation theory, the minority group (roughly 16 percent) of a population, which is the last group to try or adopt a new product or service.
- **Lean Manufacturing** - is a systematic approach to identify and eliminate waste through continuous improvement, by flowing the product at the pull of the customer in the pursuit of perfection.
- **Pareto Analysis** - is a bar chart that displays by frequency, in descending order, the most important defects or issues.
- **Prevention-Appraisal-Failure model (PAF)** - is based on Armand Feigenbaum’s Quality costing analysis and Joseph Juran’s Economics of quality model.
- **Quality Assurance (QA)** - attempts to economically improve and stabilize production, and associated processes, to avoid, or at least minimize, issues that led to the defects in the first place.

Glossary to Terms (3 of 3)

- **Quality Control (QC)** - emphasizes testing of products to uncover defects, and reporting to management who make the decision to allow or deny the release.
- **Quality Management Systems (QMS)** - A set of coordinated activities to direct and control an organization in order to continually improve the effectiveness and efficiency of its performance.
- **Roadmap** - A Roadmap is a simple project plan that is used after the Impact-Effort chart has been developed. The Roadmap has a list of the project/issues (Refer to Issue Code) that need to be addressed, a start date and end date of that project, metrics used to measure the progress and names of the team members involved in the project.
- **Root-Cause analysis** - Identification and evaluation of the reason for nonconformance, an undesirable condition, or a problem which (when solved) restores the status quo.
- **Supply Chain management (SCM)** - is the management of the entire value-added chain, from the supplier to manufacturer right through to the retailer and the final customer. It incorporates the process of planning, implementing, and controlling the operations of the supply chain with the purpose of satisfying customer requirements as efficiently as possible.
- **Six Sigma** - is a fact-based, data-driven philosophy of improvement that values defect prevention over defect detection.
- **Total Quality Management (TQM)** - is a management philosophy that seeks to integrate all organizational functions (marketing, finance, design, engineering, and production, customer service, etc.) to focus on meeting customer needs and organizational objectives. TQM empowers the total organization, from the employee to the CEO, with the responsibility of ensuring Quality in their respective products and services, and Management of their processes through the appropriate process improvement channels.
- **Value stream –** Sequence of activities required to design, produce, and provide a specific good or service, and along which information, materials, and worth flows.

References (1 of 2)

- U.S. Department of Housing and Urban Development . (2001, November). *Implementing a Quality Assurance System: A Trade Contractor Case Study.* Retrieved December 29, 2009, from http://www.toolbase.org/PDF/CaseStudies/TradeContractorCaseStudy.pdf
- Rooney, J., & Kilkelly J. (2002, February). On Today's Menu: Quality, Case study shows how HACCP helps ensure farm to table food safety. *Quality Progress,* 25.
- American Society for Quality. *Simple Process Change Saves Thousands of Dollars, Leads to Zero Production Defects.* Retrieved December 29, 2009, from http://www.asq.org/economic-case/markets/pdf/25296-case-study-mfg7.5.pdf
- American National Standards Institute. *ANSI Standards.* Retrieved December 29, 2009, from http://webstore.ansi.org/
- Quality Engineering Handbook, Thomas Pzydek, 1999.
- Best Practicess, LLC
- http://www.qualitymag.com/CDA/Articles/How_To_Supplement/BNP_GUID_9-5-2006_A_10000000000000076119
- http://www.globaltirenews.com/headlines2.html?cat=1&id=1235659385&q=Scrap+recyclers+regroup
- http://www.uwstout.edu/faculty/schultzf/apsc-311/docs/QAQC.pdf
- ADVAC Elastomers Inc
- Martin, L. (1993). "Total Quality Management in the Public Sector," National Productivity Review, 10, 195-213.
- www.isixsigma.com/library
- http://en.wikipedia.org/wiki
- http://www.businessdictionary.com
- http://www.cliffsnotes.com/WileyCDA/
- http://www.tpub.com/content/advancement/14144/css/14144_75.htm
- http://www.p2pays.org/ref/22/21379.pdf
- http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1332647/
- http://www.ncbi.nlm.nih.gov/pubmed/12737962

References (2 of 2)

- Clean Washington Center, a division of the Washington State Department of Community, Trade & Economic Development. (1996, December). *Best Practices in Scrap Tire and Rubber Recycling.* Retrieved December 7, 2009, from http://www.p2pays.org/ref/11/10670.pdf